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A STUDY OF THE FAUNA OF RIVERS POLLUTED BY LEAD MINING IN THE ABERYSTWYTH DISTRICT OF CARDIGANSHIRE

BY KATHLEEN E. CARPENTER, M.Sc.

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(With 2 Maps.)

THE deleterious effect upon river fisheries of the discharge of effluents from lead mines into the rivers has long been recognised, and has even been made the subject of legislation (1); nevertheless, and notwithstanding the fact that definite recommendations for the control of such discharge have been issued by the Ministry of Agriculture and Fisheries, it is difficult to find evidence of any thorough scientific investigation of the subject, whose complexity is undeniable. Such an inquiry appeared to promise interesting results in the Aberystwyth District, whose main rivers have been affected for some hundreds of years by lead mining carried on beside their banks (2, 3), and the investigation was accordingly commenced in 1919, since which date it has been carried on continuously.

The area chosen for study includes a strip of coast bordering on Cardigan Bay, and traversed by several rapid streams, of which the chief are the Rheidol, the Ystwyth, and the Clarach. The two former have their sources in the Plynlimon Plateau, an elevated region of anticlinal folding along a north to south axis, whose highest point (Pen Plynlimon Fawr) rises to 2468 ft. The Clarach, a shorter stream, rises on the edge of the High Plateau west of the Plynlimon ridge, at an elevation of about 1200 ft. The lower courses of all three rivers are roughly east to west across the Coastal Plateau, which slopes to about 400 ft. near the coast, whence steep cliffs descend to the sea. The local rocks are grits, flags and shales of the Valentian and Bala series; metalliferous veins occur along fault lines usually running E.N.E. to W.S.W., and mainly situated in the upper parts of the basins of the principal rivers (3).

All the streams of the district are rapid in flow, often cutting deep gorges in the middle parts of their courses, and for the most part their beds are stony. The lower valleys are often carpeted with boulder clay,

and there, in quieter reaches, the rivers are slightly turbid with the resulting mud, but as a general rule, the waters are clear and rapid, and the banks are strewn with gritty pebbles brought down by the rivers in time of flood.

The general physical character of these streams is such as to suggest that trout, salmon, etc., might be found in them in abundance, and indeed, the rivers Leri, Dyfi and Teifi, streams not far distant and remarkably similar to them in general character, have rich fisheries—yet the local rivers, Rheidol and Ystwyth, are absolutely destitute of fish-life. The Clarach, although a smaller stream, does contain a few trout, and sewin, or sea trout, may at times ascend all three rivers for a very short distance. Trout occur in relative abundance in the pools and streams of the High Plateau region, and in some of the tributaries of the larger rivers, and where this is the case the general fauna and flora are of a much richer type than in the Rheidol and Ystwyth. Streams classed as "barren" are recognisable on the most superficial inspection: their waters are clear down to the pebbles of the bed—there is only the slightest coating of moss or liverwort on any of the stones, and algal and phanerogamic vegetation are usually conspicuous by their absence, with the interesting exceptions of the algae *Batrachospermum* and *Saccheria* (Limaniaceae), which often flourish in such situations. Such scanty vegetation gives little opportunity for the accumulation of sediment, hence the extreme clearness of these streams save when they are rendered turbid by recent floods.

The barren character of such waters has always been locally ascribed, without much enquiry or definite evidence, to the influence of lead mining and crushing operations which were formerly very extensive in the district—a theory which appears to be borne out by comparison of the distribution of the lead workings with that of the barren waters. Other suggestions which might possibly be made in explanation of the existence of two distinct types of flora and fauna in the streams of a single area have been considered as follows:

A. Variations in the Substratum.

The local Silurian rocks are remarkably homogeneous in character throughout the area. Boulder clay, derived from the Plynlimon Plateau, is unevenly distributed over the area, but the mere fact of its occurrence in quantity in the valleys of Lower Clarach, L. Rheidol and L. Ystwyth alike is sufficient to discount the value of its presence as a determining factor in the issue involved.

B. Variations in the degree of acidity or alkalinity of the waters of the several streams.

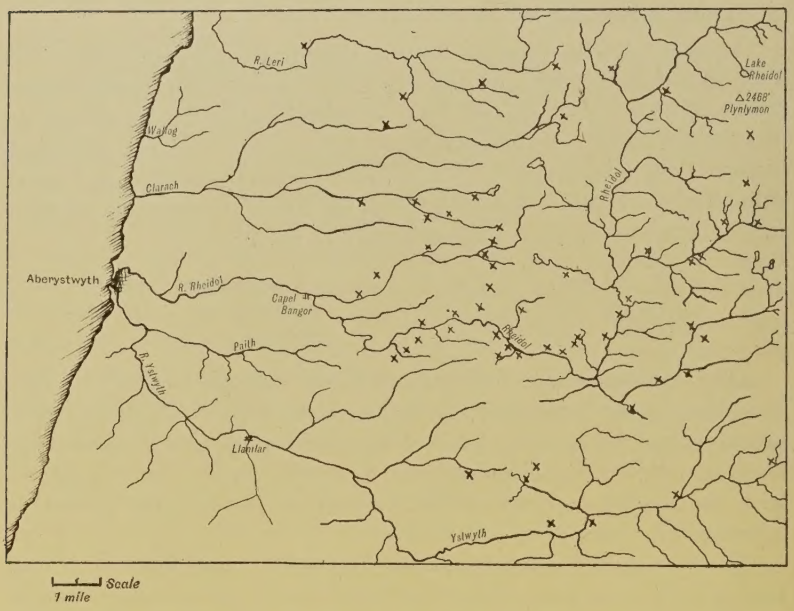
A series of water samples from representative streams within the area have been tested, and the degree of hydrogen-ion concentration determined by the colorimetric method established by Clark and Lubs (4). The general result of these investigations is to shew that the *p*H values of the waters of the various streams vary between 6·1 and 6·9, indicating slight acidity in every case, with no special line of demarcation between rich and barren streams. Examples may be given:

L. Rheidol (*barren*)	*p*H 6·4	L. Clarach (*rich*)	*p*H 6·4
L. Ystwyth „	„ 6·5	Bow Street „	„ 6·5
Nant Silo „	„ 6·6	Wallog „	„ 6·8

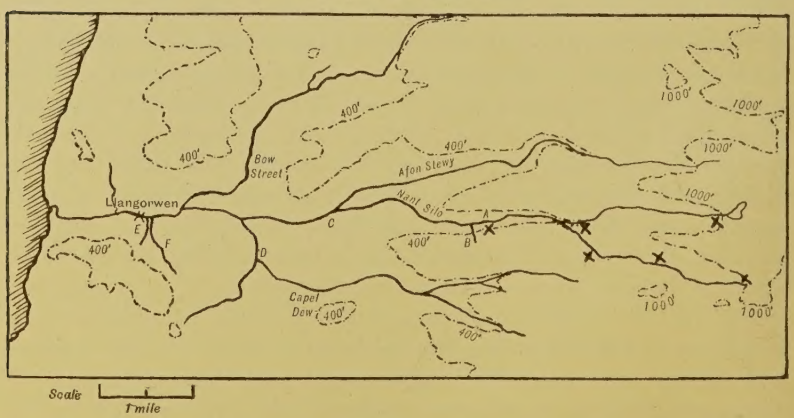
(The constant slight acidity, correlated with the scarcity of lime salts, is no doubt connected with a general poverty which characterises the freshwater fauna of the whole district, and which affects particularly the group Mollusca; but this general poverty is in no wise comparable with the special and remarkable poverty of the streams classed as "barren.")

There remains the argument that pollution consequent upon lead mining operations has seriously affected the fauna of certain waters. A glance at the map (p. 4) shewing distribution of Cardiganshire lead mines reveals the crowding of such workings around the head waters and many of the tributaries of Rheidol and Ystwyth: even this map is not quite complete, as there are many small mines unmarked upon the Ordnance Sheets, which could not in all cases be represented. Certainly all the lead mines have ceased working, many of them a considerable number of years ago, but possibilities of pollution from this source still remain. All the mine workings are situated near the banks of some stream, into which water from the mine effluents runs directly; in addition, there are open heaps of mine refuse containing material in all states of division, from rough blocks to fine sediments, much of it rich in lead ore (which occurs in the form of galena—PbS), and often covering a very considerable area of ground in the river valley. Surface drainage and wind action continually bring material from these heaps into the rivers, and that this material is actually still rich in lead is amply proved by a few chemical analyses of samples taken from the heaps. Two examples may be given: at Old Goginan Mine, a large working closed since 1886, material collected on November 1st, 1922, from the side of

Distribution of Lead Mines in N. Cardiganshire.



Valley of the Clarach.



Contour lines —•—•—• at 400′ and 1000′. Localities: A, B, C, D, E, F.

Lead mines: ×.

a mine tip facing the stream, was found on analysis to contain a percentage weight of lead amounting to 1·64 per cent. of the total weight of the dry sample. At Llywernog (closed 1883), a similar sample had percentage weight of lead 1·15. While samples taken from different parts even of the same heap may vary considerably in quality, yet there is obviously a considerable amount of lead ore present in the débris of the old workings—quite sufficient to cause serious pollution of the rivers, even if we neglect the fact that it was the ancient practice to tip the mine refuse directly into the neighbouring streams.

The topographical relationship between distribution of mine workings and distribution of barren waters has already been mentioned: an intensive study of the streams of the Clarach Basin, as reproducing in epitome many of the characteristic features of the wider area, makes this relationship particularly clear(5) (see map, p. 4).

Of the two head streams of the Clarach, Afon Stewy and Nant Silo, the latter, with its tributary from Cwm-erfin, flows through a district where lead mining has been carried on since very early times, the former, like the later affluents, Capel Dewi and Bow Street Brooks, is free from such contamination. The main stream of the Lower Clarach flows due east to west through a fine glaciated valley. A series of collections made in the area between the years 1919 and 1922 forms the basis of the following list, from which all mention of Protozoa, Nematoda and Rotifera has been omitted:

LOCALITY A. Nant Silo, near mine-effluent.

Animal species 3 (larvae).

Diptera	2	*Simulium latipes* *Tanypus nebulosus*
Ephemerida	1	*Chloeon simile*

LOCALITY C. Lower down the same stream, after the confluence with unpolluted Afon Stewy.

Animal species 7.

Diptera	2	Plecoptera	2
Ephemerida	2	Trichoptera	1

LOCALITY D. Unpolluted Capel-Dewi Brook.

Animal species 23.

Diptera	4	Arachnida	2
Ephemerida	2	Crustacea	1
Plecoptera	3	Oligochaeta	1
Trichoptera	5	Mollusca	1
Coleoptera	2	Chordata	2 (*Salmo fario*, *Gastrosteus aculeatus*)

Locality E. Main stream at Llangorwen; far below any lead mines, and after union with several unpolluted tributaries.

Animal species 47.

Diptera	4	Crustacea	7
Ephemerida	2	Oligochaeta	1
Plecoptera	3	Hirudinea	1
Trichoptera	9	Mollusca	3
Coleoptera	8	Platyhelmia	2
Hemiptera	3	Chordata	2
Arachnida	2		

Locality G. Bow Street Brook (unpolluted). Fauna list intermediate between those of D and E. (Larger brook than Capel Dewi.)

Even the small brooks labelled B and F have a richer fauna than the much larger stream at A and C; at B, a mere impermanent trickle of running water, a few minutes' search sufficed to find 8 species, while at F, 11 are represented.

Poverty of fauna in the Clarach Basin is obviously related to some factor other than the mere physical geography, and proximity of lead mines appears to be very clearly indicated as this factor, here as elsewhere in the Aberystwyth district.

A comparison between fauna lists established for various localities between the years 1919 and 1922 is interesting. The localities quoted are as follows:

A. Lower Rheidol. A fair sized river, heavily polluted by numerous lead workings.

B. Lower Ystwyth. Similar to A.

C. Lower Clarach. A smaller river, some of whose upper waters are polluted in this way, but which has several pure affluents whose total volume exceeds that of the polluted waters. Such lead workings as occur are of less recent date than those affecting Rheidol and Ystwyth.

D. Wallog Brook. A much smaller stream, totally unpolluted, very stony.

E. Llanychaiarn Brook. A tributary of the Ystwyth, totally unpolluted; has alternations of mud and stony bottom.

(The actual names of species identified are omitted from these lists, for the sake of brevity.)

In the most thoroughly polluted waters, right under the lead mines, life is not absolutely extinct: larvae of *Tanypus nebulosus*, of *Simulium latipes* and of the Ephemerid *Chloeon simile* may usually be collected here, these species appearing particularly resistant to the dangers of

	A. L. Rheidol	B. L. Ystwyth	C. L. Clarach	D. Wallog	E. Llanychaiarn
Turbellaria	—	—	×	× ×	× ×
Mollusca	—	—	× × ×	× ×	× × ×
Oligochaeta	—	—	×	×	× ×
Hirudinea	—	—	×	×	×
Crustacea-Entomostraca	× ×	× × ×	× × × × × ×	× × × ×	× × × ×
Crustacea-Malacostraca	—	—	×	×	×
Arachnida	×	×	× ×	×	×
Hemiptera	×	× ×	× × × ×	—	—
Trichoptera	—	—	× × × × × × × × ×	× ×	× × × × × × ×
Plecoptera	×	× ×	× × ×	× ×	× × ×
Ephemerida	×	×	× ×	× ×	×
Neuroptera	—	×	—	—	—
Odonata	—	×	—	—	—
Coleoptera	× ×	× ×	× × × × × × × ×	×	× × ×
Diptera	×	×	× × × ×	× × ×	× × × × × ×
Chordata	—	—	× ×	—	×
Total	9	14	47	22	35

Number of animal species indicated by ×'s.

their circumstances, and in the summer the Hemiptera *Velia currens* and *Sigara minutissima* appear also.

The complete absence from seriously polluted streams of Platyhelmia, Mollusca, Chordata, Trichoptera, Crustacea-Malacostraca, Oligochaeta and Hirudinea is always remarkable, the fauna of such streams being limited to a few insect larvae and a few Crustacea-Entomostraca, which occur usually in very small numbers.

The economic, as well as the scientific, interest of the study of the biology of lead-polluted streams is considerable, in view of the financial losses caused by such pollution: even to the casual observer, the desolation of these waters suggests the desirability of protecting the streams in districts where fresh mines are being opened or where the consequences of mining activity are not yet too serious for correction. Any such protective measure in the interest of river fisheries must, if it is to be effective, be based upon thorough investigation of the manner in which lead pollution affects the whole population of the stream—not merely the fish themselves, not merely the fishes and their food organisms, but all the organisms which coexist with them, and all of which must be regarded as affecting the general equilibrium of life in the streams.

The first steps in such an investigation in the Aberystwyth district, which led to the establishment of comparative tables of river fauna, some of which are quoted above, established the conclusion that lead pollution serves to impoverish the whole fauna of the streams, affecting all groups

in general, and tending to eliminate altogether the Fishes, Platyhelmia, Mollusca, Annelida and Trichoptera. The actual nature of the selective factor and its mode of operation could only be sought by inquiry into the chemical and physical conditions set up in the streams themselves.

Direct evidence of immediate effects of the discharge of mine effluents into hitherto unpolluted streams could not be collected in this district, as no new lead mines have been opened recently, but the conditions consequent upon such discharge continue to prevail in some cases for a number of years and may be summarised as follows. First, a large amount of solid mine débris containing galena particles in various states of division, from quite large particles to very fine gritty dust, finds its way into the rivers in the fashion already described. Second, the river water in its natural state is capable of exerting considerable chemical action upon the lead ore, with the result that lead compounds (probably the oxide and hydroxide) are found in actual molecular solution and also in the colloid condition in the waters thus affected. In times of flood, the waters of lead-polluted streams near Aberystwyth have been seen to have an opalescent appearance from the presence of material in the colloidal state, and plants growing on the banks appear slightly coated with slime after subsidence of the floods.

The presence of lead salts in solution (molecular and colloidal) in the polluted waters has been demonstrated by chemical tests which have been made incidentally to the biological investigation: of the actual chemistry of these compounds little can be said, as chemical specialists do not appear to have paid much attention to these phenomena, but it seems probable that the action of river waters on galena particles has many analogies with that of natural waters on lead foil, which has been so thoroughly investigated by Dr J. C. Thresh, of the Counties Health Laboratory (6). Dr Thresh's recent work has exploded the old theory that the plumbo-solvent power of water depended upon its acidity, and has established the importance of the presence of silicic acid and silicates as retarding agents in the process of lead solution. The character of such waters in the Aberystwyth district as have been proved to contain dissolved lead salts is such as to support the probability of the analogy suggested, these waters being unusually free from the usual dissolved salts, including silicates.

There would thus appear to be two possible sources of danger to the population of lead-polluted streams—danger from the presence of gritty particles of lead ore, such as might cause mechanical injury to

delicate tissues, and danger from the presence of lead salts in diffusible form (whether in actual molecular solution or in "colloidal solution"), such as might exert either a chemical action from without upon epithelial tissues and secretions, or a toxic action from within after absorption. In the first case, probably mechanical injury alone need be considered, since it is well known that large amounts of lead in solid form may pass through the body after being swallowed, with practically no absorption, even under the action of the digestive fluids, and without fatal effects. This has been clearly shewn by Dr T. W. Hogg in the case of earth-worms (7).

Two lines of investigation seem indicated. The possibility of mechanical injury from the presence of gritty particles is the only one to which serious attention has hitherto been paid by those interested in the preservation of river fisheries: the general theory has been that fishes are directly affected by the stirring up of rough galena grit from the river bottom, particles of which adhere to the gill filaments and there set up inflammation which ultimately causes death. On this theory, and on this alone, are based the recommendations framed by the Ministry of Agriculture and Fisheries for issue to owners of lead mines, in which recommendations there is insistence upon a method of sedimentation by passing the water of the mine effluent through tanks. In these tanks it is allowed to stand until sedimentation is considered to be complete, then run off from a high level. This is simply the equivalent of a rough filter method.

In support of the general theory referred to, I am permitted to quote evidence collected by Prof. Fleure at the time of the opening of the Hafan mine affecting the Leri in 1913; his statement is as follows:

"I found that these fish had rough grit and galena fragments between the gill filaments, and that these fragments had set up inflammation. A post mortem did not reveal anything wrong internally."

Further observation along these lines is desirable, but difficult to carry out, as it is by no means every day that a new mine is opened, affecting a hitherto unpolluted stream.

Indirect evidence has been sought in another way: by the quantitative chemical analysis of samples of finely divided grit, capable of being carried in suspension by swiftly moving water. These samples were obtained from the beds of local streams by dragging along in an up-stream direction a small bag of silken tow-netting in a rigid frame, held in such a position that one side of the square frame just touched the surface of the bed.

The results of analysis may be tabulated as follows:

Locality	Description	% weight of lead in dry wt. of whole sample
A. L. Rheidol (Pen y Bont)	Fauna and flora extremely poor. Streams directly affected by extensive mining operations above these points	0·085
B. L. Ystwyth (Rhyd y Felin)		0·01
C. L. Clarach (Llangorwen)	Rich flora and fauna. There are lead workings near some of the higher tributary streams	0·12
D. Nant Silo	Fauna extremely poor. Sample taken just below an old lead working. This is a tributary of the Clarach	0·035
E. Gogerddan	Lower down the same tributary, after confluence with an unpolluted stream. Fauna intermediate	0·015
F. Wallog	Large brook—no lead mines affecting it. Fauna relatively good	0·01
G. Llanychaiarn	As above	0·012
H. Plas Hendre	A mere trickle of water, almost a roadside ditch	0·005

It should be noted that these figures are not absolute in themselves: a sample taken at a few yards' distance or at a day's interval might have yielded quite a different figure, nevertheless the records serve to establish two conclusions:

(1) Lead ore is present in gritty particles in the beds of streams which are absolutely unaffected by mining operations (it is in such cases certainly derived directly from the substratum, whether from the bed rock or from drift deposits).

(2) The poverty of fauna in the streams classed as "lead polluted" cannot be directly related to the presence of grit of this kind.

As regards the fishes themselves, we have the direct evidence quoted above that adhering gritty particles have been known to cause inflammation of the gills; but the question remains whether such a condition is referable to the nature of the particles, as galena fragments (in which case some kind of chemical action seems presupposed, the lead passing into diffusible form), or whether the injury is merely mechanical, and thus one to which fishes are exposed in any stream which bears along gritty fragments of whatever chemical nature—for example, in the neighbourhood of quartzite quarries. Of injury to fishes in such cases as the latter I have no evidence. At all events, the fact that trout, sticklebacks and elvers are found living in streams of the Aberystwyth district where a proportion of the sediment can be proved to consist of gritty fragments of lead ore (notably in the Clarach at Llangorwen, where both *Salmo fario* and *Gastrosteus* occur), proves indisputably that fishes are capable of existing under such conditions.

As regards the invertebrate population, the same argument holds good, nor is it reasonable to suppose that the larvae of Trichoptera such as *Limnophilus*, in their protective cases through which the respiratory current is drawn by a fine perforation in the closing membrane, nor the more minute and delicate species of aquatic animals, which escape many dangers by reason of their smallness, can be very seriously in danger of mechanical injury from rough grit.

So far as direct evidence goes, nothing more can be asserted with regard to the significance of the presence of lead ore in gritty particles than that the observed facts in the Aberystwyth district clearly shew that such a condition is by no means incompatible with the existence of a relatively rich fauna, including fishes and several of their more important food-organisms.

A second possibility remains: that the presence of lead salts in diffusible form (molecular or colloidal solution) may act as a selective factor upon the natural fauna of the streams. The toxic action of lead in such diffusible form when absorbed into the system has been studied in the human subject by various workers, and in the cases of chronic lead poisoning or "plumbism" which ensue upon such absorption the destructive action is extremely slow and the amounts absorbed into the system are relatively small(8). The suggestion of a similar action upon river fauna is an attractive one.

Few workers have investigated the action of dissolved lead salts upon animals immersed in water: the researches of Drs Penny and Adams in 1863 established the fact that lead acetate in a proportion of 1 to 4000 (*i.e.* 250 milligrammes per litre) is directly fatal to minnows and goldfishes(9). More recently, Mr J. Rushton(10), working with solutions of lead nitrate, records a strength of 1 in 100 as fatal to trout within 15 minutes, a smaller proportion of 1 in 100,000 having similar effects in 2 hours and 15 minutes.

Several facts should be noted in connection with these experiments:

(1) In each case the solution used is artificial in character: lead nitrate and lead acetate are convenient for laboratory use, being readily soluble, but it is not in such form that lead salts occur naturally in waters of mining areas.

(2) The proportions used, even in the last-quoted instance, are relatively enormous, and such as are not likely to occur in any stream under ordinary conditions. The reaction thus becomes rapid, and the experiments afford no parallel with lead poisoning of the cumulative type, known in the human subject.

(3) There has been no use of "colloidal lead" such as occurs in natural waters below the mines.

(4) Fish have been the sole subjects of experiment; their invertebrate food organisms have not been exposed to similar tests.

These experiments can therefore throw no light on the topic under discussion, except in so far as they establish definitely the contention that the presence of lead salts in solution may have a fatal effect upon Fishes.

In order to discover whether any correlation might be supposed to exist in the Aberystwyth area between impoverishment of fauna and presence of lead salts in diffusible form, water samples were collected from streams of very different types and a series of estimates of amount of lead present "in solution" (including molecular and colloidal solution, where the latter will pass through a filter paper), were made by the method advocated by Clowes and Colman(11).

The early series of determinations—1921 to spring of 1922 were as follows:

Date	Locality	Lead (mgr. per litre)	Type of fauna
Feb. 16–20, 1921	1. Lower Rheidol	0·2	A
	2. Lower Ystwyth	0·5	A
	3. Upper Clarach (at Nant Silo lead mine)	0·2	A
March 1–15, 1921	4. Llanychaiarn	—	B
	5. L. Ystwyth	0·4	A
	6. L. Rheidol	0·5	A
	7. Elysian Grove	—	B
	8. Lower Clarach	—	B
March 20, 1922	9. Wallog	—	B
„ 23, „	10. L. Rheidol	0·2	A
„ 27 „	11. L. Ystwyth	0·4	A
„ 29, „	12. L. Clarach	—	B
„ 29, „	13. Nant Silo	0·5	A

These figures seemed to indicate a definite relation between presence of lead in diffusible form and poverty of fauna (in waters of type A—hereafter referred to as the "polluted" type), contrasted with comparative wealth of fauna in streams of type B ("non-polluted"). So far, all the tests made shewed lead in readily-diffusible form to be invariably present in streams of type A, although a comparison of figures (1), (6) and (10), or of (2) and (11) gave evidence of some variation in amount present. This latter fact did not affect the general relation stated above, and it seemed probable that the actual determining factor in the impoverishment of lead-polluted streams was presence of lead salts in diffusible

form rather than presence of galena grit, although the latter might perhaps be directly harmful in some cases.

In the late spring of 1922, a long period of drought followed upon a winter of, on the whole, sub-normal rainfall (see rainfall tables). Probably also the water shortage consequent on the long summer drought of 1921 had not been made up: however this may be, in May and early June of the year 1922 the rivers of this district were very much lower than had been the case for many years, even in the preceding summer. By the end of May, many of the smaller brooks were altogether dried up, and the larger rivers in spite of their numerous tributary streams rising in the High Plateau, were greatly diminished in volume. In many parts of Lower Rheidol and Ystwyth the stream was seen to occupy only about half of its usual bed, exposing broad, flat surfaces of pebble deposits, and it was almost possible to walk dryshod from boulder to boulder across the Rheidol, our largest river, only a mile and a half above the sea. At this spot (near Pen y Bont), where usually a clear stream rushes over smooth boulders and pebbles, only a few of which are overgrown with Bryophytes or with the Alga *Saccheria*, masses of aquatic Phanerogams (*Ranunculus aquatilis* and *Callitriche verna*), made their appearance in the main stream and rapidly increased in size, while the usual Algal and Bryophyte vegetation was considerably augmented.

Observation of these changes suggested the advisability of making a careful re-examination of the fauna, which also was found to have undergone very considerable alteration, as shewn by the comparative table on p. 14.

(N.B. The fauna is in all cases that of the main stream, and not that of either temporary or permanent "cut-offs," which may be understood to be influenced by conditions different from those affecting the river itself.)

The total number of species had thus more than doubled itself; but a mere list of species can give no idea of the astonishing character of the change. A locality where on previous visits a few specimens only had with difficulty been collected now exhibited a positive wealth of animal life: not only did the new species establish themselves in considerable numbers, but species previously recorded (e.g. *Chloeon simile* and *Tanypus nebulosus*) were now represented by multitudes of individuals. The most remarkable feature of the change was the incursion of eight species of Trichopteran larvae into a region where they were hitherto unknown (at any rate since 1919, up to which date no records existed). Almost every pebble picked at random out of the river bed bore the pebble cases of *Rhyacophila* or of *Agapetus*; the minute horn-

Fauna of the Lower Rheidol.

	Species recorded previous to spring, 1922		Species collected in and after May, 1922	
Platyhelmia	—	0	Polycelis nigra	1
Crustacea	Cyclops serrulatus		Cyclops serrulatus	
	C. prasinus		C. prasinus	
	—		Canthocamptus minutus	
	Eurycercus lamellatus ...	3	Eurycercus lamellatus ...	4
Arachnida	Sperchon glandulosus ...	1	Sperchon glandulosus ...	1
Hemiptera	Notonecta glauca		Notonecta glauca	
	Sigara minutissima ...	2	Sigara minutissima ...	2
Coleoptera	Dyticus marginalis		Dyticus marginalis	
	Hydroporus rivalis		Hydroporus rivalis	
	—		Hydraena riparia	
	—	2	Gyrinus natator ...	4
Plecoptera	Chloroperla grammatica		Chloroperla grammatica	
	Leuctra nigra ...	2	Leuctra nigra ...	2
Ephemerida	Chloeon simile		Chloeon simile	
	—	1	Ecdyurus venosus ...	2
Neuroptera	Sialis flavilatera ...	1	Sialis flavilatera ...	1
Odonata	Platycnemis pennipes ...	1	Platycnemis pennipes ...	1
Diptera	Tanypus nebulosus		Tanypus nebulosus ...	
	—		Simulium reptans	
	—	1	S. latipes	3
Trichoptera	—		Rhyacophila obliterata	
	—		Agapetus fuscipes	
	—		Crunoecia irrorata	
	—		Hydropsyche angustipennis	
	—		Plectrocnemia conspersa	
	—		Anabolia nervosa	
	—		Limnophilus decipiens	
	—	0	Mesophylax impunctatus	8
	Total number of species	14		29

shaped tubes of *Crunoecia* clustered in vast numbers around the tufts of Water-Starwort; and in some places the bed of the river, usually clear and light owing to the pebbles which strew it, shewed dark brown shoals of *Anabolia* and *Mesophylax* through the water. The change was so striking that any description of it after the event has an effect of exaggeration: still, there remains the no less striking corroborative fact of the sudden establishment of aquatic flowering plants, noticed also by members of the Botanical Department of the University College and commented upon even by the unscientific observer.

The new record of *Polycelis nigra* is also interesting, this being the first Planarian found in this locality. A very marked feature of the change in general was the introduction of species of which the majority evince a direct dependence upon the aquatic vegetation, *e.g.* Caddis larvae such as *Anabolia*, which make their tubes of vegetable matter, *Polycelis*, which crawls over the leaves of water plants, *Canthocamptus* and *Hydraena*, which shelter among the tangle of fronds.

In the early days of the invasion there seemed to be a slight shortage of vegetable matter in proportion to the new animal population: this was illustrated by the behaviour of certain of the Caddis larvae which make their cases of vegetable fragments. Many *Anabolia* were found at this time (about June) with the posterior half of the case shewing the normal structure, the anterior portion a patchwork of small, flat pebbles, or even of the cases of smaller members of the species, whose occupants were still living.

The new conditions in the Rheidol were traced $5\frac{1}{2}$ miles up stream to Capel Bangor.

In the Ystwyth, between Llanilar and Rhyd y Felin, an analogous series of changes took place. Among the flora, the incursion of Chlorophyceous Algae, forming tufted growths upon the pebbles, was particularly marked; the new fauna list presented 25 species as against the 9 of previous records, and here again one Planarian (in this case, *Dendrocoelum lactum*) made its appearance, while the new Trichopteran species numbered 7, the list differing slightly from that established for the Rheidol.

Fauna of the Lower Ystwyth.

	Species collected previous to May, 1922		Species collected in and after May, 1922	
Platyhelmia	—	0	Dendrocoelum lacteum ...	1
Crustacea	Cyclops serrulatus		Cyclops serrulatus	
	Eurycercus lamellatus ...	2	Eurycercus lamellatus ...	2
Arachnida	Sperchon glandulosus ...	1	Sperchon glandulosus ...	1
Hemiptera	Notonecta glauca		Notonecta glauca	
	—		Gerris paludum	
	—	1	Sigara minutissima ...	3
Coleoptera	Dyticus marginalis		Dyticus marginalis	
	Hydroporus rivalis		Hydroporus rivalis	
	—		Hydraena riparia	
	—		Elmis volckmari	
	—	2	Limnius tuberculatus ...	5
Plecoptera	Leuctra nigra		Leuctra nigra	
	—		Chloroperla grammatica	
	—	1	Isogenus nubecula ...	3
Ephemerida	Chloeon simile		Chloeon simile	
	—	1	Ecdyurus venosus ...	2
Diptera	Tanypus nebulosus		Tanypus nebulosus	
	—	1	Simulium latipes ...	2
Trichoptera	—		Rhyacophila obliterata	
	—		Agapetus fuscipes	
	—		Silo nigricornis	
	—		Brachycentrus subnubilus	
	—		Plectrocnemia conspersa	
	—		Hydropsyche angustipennis	
	—	0	Mesophylax impunctatus	7
	Total number of species	9		26

In both rivers, the new condition had all the characteristics of an invasion by a population coming from the smaller tributary streams, which support a flora and fauna usually unable to exist in the main river. This was particularly well illustrated round about the confluence with the Ystwyth of the Llanychaiarn brook, which latter, though of no great size, has a relatively rich fauna. At the season mentioned, the brook was almost dried up, but stones picked from the bed of the river near the confluence (above as well as below, though in a lesser degree) were thickly set with cases of *Agapetus* or of *Hydropsyche*, both of which are at all seasons common in the brook. In all probability there was direct immigration of individual larvae from their original homes: the date of the incursion makes this obvious, as all the larvae were found in May, whereas in no case except that of *Brachycentrus subnubilus* does the imago appear prior to that month, and in several the date is much later (*Anabolia nervosa*—August). This direct immigration is not so surprising as it may appear, since all the larvae are capable of active movement: even *Rhyacophila obliterata* often wanders far from its fixed case, while *Agapetus fuscipes*, a very delicate form which makes a completely floored pebble case of relatively enormous weight, can move actively about the Laboratory aquarium carrying its case with it, though it prefers as a rule to cling to a stone.

As an explanation of these remarkable changes in the fauna of the two rivers, any suggestion of a mere seasonal variation must be dismissed, since collections made at corresponding seasons in the preceding years of 1919–1921 had formed the basis of the standard lists of 14 and 9 species only for Rheidol and Ystwyth respectively.

A second possibility suggested itself: that of a down stream migration in consequence of drought (Shelford(12) has shewn that migrations of this and of the up-stream flood type are not confined to Fishes); but this alone is not sufficient to explain the facts. Such a migration has not been known to take place in these particular localities of recent years (notably in the dry season of 1921); from the former distribution of species, very serious changes are seen to be involved, and it is difficult to understand how the newcomers could maintain life in the polluted waters of streams hitherto rendered barren almost from their sources by lead contamination. That life was maintained was evinced by a series of collections made after heavy floods in September of the same year, and in the following spring. During the winter months, when it was of course impossible to compile full lists, as many as 11 of the 15 new species in the Rheidol and 12 of the 17 in the Ystwyth were found to

be represented, while in March and April of 1923 the numbers were found to be complete, with the following additions:

Rheidol (Pen y Bont), four species:

Corixa limitata,	Limnebius truncatellus,
Agabus bipustulatus,	Chironomus plumosus;

Ystwyth (Rhyd y Felin), four species:

Planaria alpina,	Anabolia nervosa,
Velia currens,	Deronectes latus;

shewing that the process of repopulation was being continued.

Since paucity of fauna in the area had been consistently related to lead pollution, it was conjectured that the long continued drought, by reducing the amount of surface drainage over the mine heaps, might have produced a diminution in the lead content of the lower rivers. Samples were accordingly taken (in June, 1922), and subjected to quantitative analysis, which gave results as follows:

Locality	Lead in water sample	Lead in grit sample
Pen y Bont (L. Rheidol)	None	0·085 %
Rhyd y Felin (L. Ystwyth)	None	0·01 %

These figures give definite support to the original contention regarding the importance of lead salts in diffusible form.

Probably the drought conditions were not alone responsible for the reduction in lead content of this kind: a contributory cause was no doubt the complete cessation of the last of the local lead mining and washing operations. Until quite recently a few lead mines re-opened during the war had been active, but the last of these affecting the Rheidol (at Rhiwfron and at Melindwr, Goginan) ceased working in 1920 and 1921 respectively, while near the Ystwyth there remained only one centre of activity at Grogwynion, where machinery formerly used for crushing lead ore was now employed upon zinc alone. Doubtless the establishment of the drought soon after the complete cessation of lead washing operations was responsible for the sudden diminution in lead content.

In view of the remarkable reduction in diffusible lead content at the time of the drought, it was decided to investigate the variation in quantity from time to time, taking samples under different weather conditions, mainly at Pen y Bont. Rainfall records are appended, for comparison with the table which follows:

Locality	Date	Diffusible lead content
Pen y Bont (L. Rheidol)	Oct. 24, 1922	0
	Nov. 2 „	0
	„ 7 „	0·05 mgr. per l
	„ 8 „	0·05 „
	„ 17 „	0
	„ 27 „	0
	Dec. 14 „	0
	Jan. 13, 1923	0
	Feb. 2 „	0·1 mgr. per l
	„ 10 „	0·1 „ „
	„ 28 „	0·1 „ „
	Mar. 16 „	0·1 „ „

The diffusible lead content is seen to be very variable in quantity, and, in fact, not present at all in appreciable amount except at times of flood; even then, the figure is low as compared with the old estimates, which ranged from 0·2 to 0·5 milligrammes per litre.

Two samples were taken from the Ystwyth at Rhyd y Felin, on October 24th and November 17th respectively: neither gave any indication of lead in the filtrate.

Samples from streams of "unpolluted" type B, also gave no result from tests of the filtrates; these were taken as follows:

Llangorwen (L. Clarach): November 19, December 15, 1922, January 31, and February 3, 1923.

Bow Street Brook: December 15, 1922.

Capel Dewi Brook: November 10, 1922.

A sample from under a lead mine at Nant Silo (Upper Clarach), on March 5th, 1923, had a lead content of 0·05 mgr. per litre in the filtrate, and a similar figure must be recorded for a sample from under the Rhiw-fron (Rheidol) workings, taken on March 9th.

There has undoubtedly been an improvement in the condition of the lead-polluted waters, which has been in part maintained in spite of very heavy rains during the latter half of December and the whole of January and February, 1923. The parallel improvement in fauna of Lower Rheidol and Ystwyth has also been maintained, and this in full, as mentioned above.

A collection made some miles higher up the Rheidol, at Rhiw-fron, on March 9th, 1923, included the following species, all of which were abundantly represented:

Dendrocoelum lacteum,
Gerris paludum,
Velia currens,
Chloeon simile,
Chloroperla grammatica,
Plectrocnemia conspersa,
Hydroporus rivalis,
Tanypus nebulosus,
Simulium latipes.

This record, from a locality which formerly was practically devoid of animal life, together with the fact of the establishment of much new growth of filamentous green Algae on the stones of the river bed, shews that the improvement is not confined to the lowest course of the river, but extends up into the former mining area.

The general conclusion drawn from observation of the changed conditions is that the presence of a diffusible lead content varying up to 0·1 mgr. per litre, together with lead grit in the river sludge, is no barrier to the establishment of a fairly rich invertebrate fauna. No Mollusca have as yet made their appearance in the streams in question, and no Fishes, with the exception of occasional trout, which stray in from the tributaries, to meet an untimely end, and of sewin, which sometimes find temporary shelter in the lower pools, returning ultimately to the sea. The general improvement in flora and fauna has, however, been so marked and rapid as to lead one to speculate on the possibilities of complete rehabilitation, such as tradition asserts to have occurred at least once in these streams, during the period prior to the revival of mining activities in the early nineteenth century. It may be that the restoration of the invertebrate fauna is an initial step in the process of rehabilitation, but it is unwise either to prophesy completion or to speculate on a method of controlling the pollution due to lead-mining in general without much more definite knowledge of the actual nature and working of the destructive agent. The circumstantial evidence derived from local study and reported in these pages, while strongly favouring the importance of dissolved lead-compounds as the active agent, is not in itself conclusive: its strongest claim is to furnish data which may be used as guiding principles in the conduct of a method of direct experimentation in field and laboratory. Such a method is now in use, and gives reasonable promise of a series of results from which conclusions of a definite character may be drawn, and which may be reported at no far distant date.

SUMMARY.

1. The relative poverty of the fauna and flora of certain streams in the Aberystwyth district can only be related to their pollution by lead mining and lead washing operations.

2. Such operations affect the rivers by the discharge into their waters of galena particles in all stages of division, and also by the formation of lead salts in diffusible form through chemical interaction with the natural water.

3. Only a single case is known of the clogging of fish-gills by

adhering particles of galena-grit: there is no definite evidence that this is a usual cause of death.

4. Statistics locally collected shew, however, that such lead grit is present in practically all the streams of the neighbourhood, particularly in the Lower Clarach, where a rich fauna, including Fishes, subsists.

5. The correlation of fauna lists with tables of analyses of water samples shews that poverty of fauna, with absence of fishes in particular, always accompanies the presence of lead salts in diffusible form.

6. The cessation of the last of the lead mining and washing operations affecting the Rheidol and Ystwyth was followed by a marked and rapid increase in the flora and fauna of the rivers, which was accelerated by the spring drought of 1922. At this season, the amount of lead in diffusible form in these waters was, if any, too small to be estimated, while the proportion of lead grit remained high.

7. Observations made since May, 1922, shew that the original proportion of lead in diffusible form has not been restored, while the flora and fauna have continued to increase.

8. The general inference is that, while the presence of lead grit is no doubt in some cases directly harmful to Fishes, the general fauna of the rivers is undoubtedly impoverished by the presence of lead salts in diffusible form.

More conclusive evidence is hoped for as the result of the employment of an experimental method based on the data reported above.

Rainfall Statistics.

A. Records from Castle Point Station, Aberystwyth. Prior to June, 1922.

Annual rainfall for	1911	32·24″	1916	30·69″
,, ,,	1912	36·71	1917	33·62
,, ,,	1913	36·17	1918	36·16
,, ,,	1914	32·25	1919	32·87
,, ,,	1915	25·30	1920	42·10

Average annual rainfall 1911–1920 33·81″

Annual rainfall for 1921 26·58″ (7·23″ below average)

Rainfall for Jan. to June, 1922 14·03″:

[Jan. 3·76″	Mar. 2·67″	*May 1·38″
Feb. 3·76	*Apr. 1·76	*June 1·00]

* Directly precedent to drought conditions which accompanied the changes in fauna of L. Rheidol and L. Ystwyth.

B. Records from Castle Point, Aberystwyth, and from Devil's Bridge, to accompany tables of water analysis (the rainfall at Devil's Bridge is important as influencing the condition of streams rising in the High Plateau).

	October 1922		November 1922	
	Devil's Bridge	Castle Point	Devil's Bridge	Castle Point
1	0·01	—	0·34	0·08
2	—	—	0·02	—
3	0·05	0·02	0·05	0·13
4	0·26	0·23	0·04	—
5	0·52	0·10	0·56	0·30
6	—	—	0·63	0·33
7	—	—	0·02	0·07
8	—	—	0·10	0·06
9	—	—	0·01	0·01
10	—	—	0·30	0·12
11	—	—	—	—
12	—	—	—	—
13	—	—	0·01	—
14	—	—	0·01	—
15	—	—	—	—
16	—	—	0·01	—
17	—	—	—	—
18	—	—	—	—
19	0·02	—	—	—
20	—	—	0·03	0·03
21	—	—	—	—
22	—	—	0·01	0·10
23	—	—	0·02	—
24	—	—	—	—
25	—	—	—	0·01
26	—	0·01	0·06	0·01
27	—	—	0·13	0·12
28	—	—	—	0·01
29	—	—	0·01	—
30	—	0·01	0·17	0·08
31	0·77	0·26	—	—
Total ...	1·63	0·63	2·53	1·46

	December 1922		January 1923	
	Devil's Bridge	Castle Point	Devil's Bridge	Castle Point
1	0·19	0·02	0·29	0·18
2	0·01	0·01	0·55	0·16
3	0·01	0·01	—	0·01
4	0·08	0·02	0·12	0·01
5	0·08	—	0·08	0·40
6	—	—	0·67	0·63
7	0·13	0·06	1·84	0·18
8	0·13	0·03	0·52	0·10
9	—	—	0·31	0·01
10	—	—	0·04	0·02
11	0·01	0·02	0·04	—
12	0·07	—	—	—
13	0·04	—	0·26	0·12
14	0·70	0·72	0·04	—
15	0·07	0·03	0·23	0·03
16	0·13	0·08	0·02	—
17	0·07	0·04	0·11	0·10
18	0·13	0·12	0·08	—
19	0·49	0·44	0·64	0·25
20	0·20	0·02	0·07	0·02
21	0·63	0·24	0·21	0·04
22	0·73	0·39	0·02	0·03
23	0·33	0·06	0·02	—
24	0·46	0·13	—	—
25	0·29	0·05	0·05	0·02
26	0·36	0·43	0·02	0·01
27	0·36	0·12	0·05	—
28	0·06	0·20	0·78	0·27
29	0·48	0·24	0·90	0·23
30	0·16	0·22	0·40	0·08
31	0·01	0·01	0·49	0·21
Total ...	6·41	3·71	8·85	3·11

	February 1923		March 1923	
	Devil's Bridge	Castle Point	Devil's Bridge	Castle Point
1	1·01	0·14	0·18	0·10
2	0·02	0·14	0·05	0·03
3	—	0·01	0·26	0·05
4	—	—	0·06	0·07
5	0·04	0·01	0·06	0·03
6	0·75	0·46	0·31	0·17
7	0·86	0·76	0·24	0·04
8	0·08	0·01	0·01	—
9	0·22	0·08	—	—
10	0·32	0·22	—	—
11	0·22	0·06	0·02	—
12	0·57	0·46	0·11	0·02
13	0·52	0·30	0·14	—
14	—	—	—	—
15	0·13	0·06	—	—
16	0·71	0·27	—	—
17	0·63	0·65	—	—
18	0·64	0·16	—	—
19	—	—	—	—
20	0·24	0·06	—	—
21	0·35	0·22	—	—
22	0·30	0·04	—	0·10
23	0·05	—	0·08	0·10
24	0·15	0·09	—	—
25	0·41	0·27	—	—
26	0·87	0·31	0·03	0·01
27	0·41	0·08	0·13	0·02
28	0·60	0·17	0·34	0·18
29	—	—	—	—
30	—	—	0·41	0·27
31	—	—	0·04	0·01
Total ...	10·10	5·03	—	1·20

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APPLES ATTACKED BY THE LARVAE OF THE DOCK SAWFLY (*AMETASTEGIA* (*TAXONUS*) *GLABRATA*, FALLÉN)

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(With 3 Text-figures.)

In October 1922 specimens of apples each with one or more small holes bored into them were received from a fruit farm in East Norfolk.

I had not previously seen damage similar to this and was surprised to find on cutting open the apples greenish sawfly larvae which resembled a number of leaf-eating forms. On breeding the sawfly we found it to be *Ametastegia* (*Taxonus*) *glabrata*, Fallén.

The grower stated that about 1 per cent. of the variety Lord Derby and also a few Bramley's Seedlings were attacked. The apples had previously been picked from the trees and stored in a large barn.

Historical and Distribution.

This sawfly was described in Sweden by Fallén in 1808. Cameron says: "It is a very common and universally distributed species." It was first recorded as a pest of apples by Fletcher in Canada in 1903, and several investigators have since recorded damage similar to the above in America and Canada, where an injury of 10 per cent. of the crop is the maximum recorded.

A full description of the life history in America and the damage caused by this pest is given by E. J. Newcomer in *Bulletin* 265, U.S. Department of Agriculture. It has previously been recorded as boring into apples in this country by Theobald in 1917 at Allington, Kent (*Monthly Reports to the Ministry of Agriculture*). The larvae are usually found feeding on the various species of *Rumex* and *Polygonum*, but have been recorded on other plants such as sugar beet, loosestrife (*Lythium salicaria*) and *Viola tricolor*. I have only found it feeding on species of *Rumex*.

Nature of Injury. (See fig. 1.)

The injury to the apples consists of small holes about 2 mm. in diameter, the edges of which are brownish in colour, and also of burrows of similar diameter and of varying lengths. Frass is usually present near the holes, which are present anywhere on the surface of the apple, and apparently as frequent in one part as another. Newcomer says: "These holes may occur anywhere on the surface, but are more

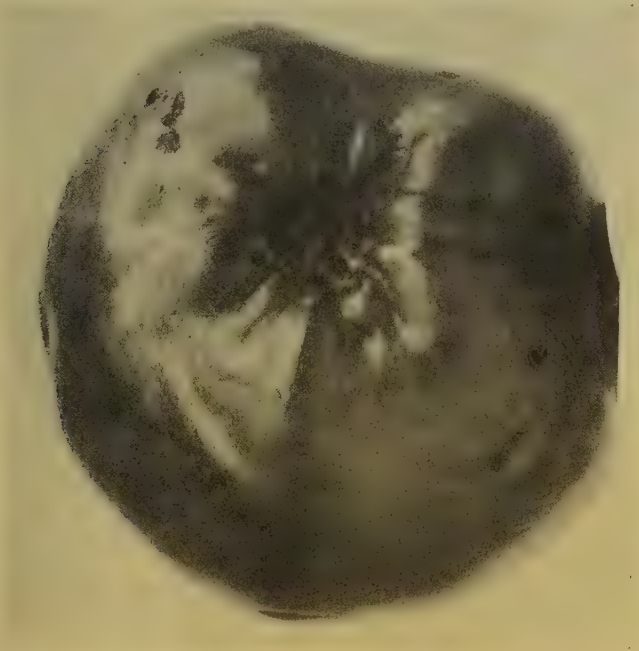

Fig. 1 *a*. Lord Derby apple showing holes and frass made by *Ametastegia glabrata*.

numerous about the calyx and stem end, or at a point where the apple touches a leaf or another apple, since it is easier for the larvae to obtain a foothold here."

The burrows vary from less than a quarter of an inch to about two inches long. They also vary considerably in shape, some being straight and others curved. A few of them reached to the core and some were semi-circular with an entrance and an exit hole. The number of burrows

in individual apples varied from one to six and a large percentage of the burrowed apples contained no larvae. Some of the burrows were larger at the ends and here the larvae were found facing the holes and here they eventually made their pupal cases.

The damage may easily be distinguished from that of the Codlin Moth caterpillars by the fact that the burrows rarely reach the core.

Fig. 1 *b*. Bramley seedling apple showing hole made by *Ametastegia glabrata*.

They do not bore into the eye nor do they eat the core as the codlin moth caterpillars do.

The apple sawfly (*Hoplocampa*) larva is earlier in the season, makes a much larger burrow, and does much more damage.

The holes made by the dock sawfly larvae naturally provide easy access for the spores of various fungi and, as expected, many of the apples began to rot round the holes. The tissue round the pupa case became very dry and did not suffer from wet rot like the tissue along

the beginning of the burrow. Some of the burrowed apples kept until the end of March without showing signs of rot.

Hibernation. For fear that the larvae might be drowned by the juice of the rotting apples most of them were removed and placed in the ends of old raspberry canes, from which the pith had been scooped out, as this was thought to approximate their normal method of hibernation. In some cases the dried apple tissue surrounding the larva was removed with it. They were kept under the roof where the temperature approximates that of natural conditions.

The larvae remained all through the winter without pupating. The first pupation took place on March 5th, but this was probably abnormally early, as on April 5th an ichneumon parasite emerged through a round hole at the head end. This was identified by Dr Otto Schmiedekneckt as *Mesoleius armillatorius*, Gravenhorst, which is not uncommon in Great Britain.

The normal larvae remained as such much longer, the first pupa was not formed until April 28th and from this I obtained a female sawfly on May 8th. Most of the remainder pupated in May, but one larva did not pupate until after the middle of June. The sawflies come out in May and June.

Life History.

Cameron says: "there are two broods of larvae, the first in June and July and the second from August to September, and this last generation seems to be the larger of the two."

This agrees with my observations, as I found adult larvae only in July and early August and at the end of September and beginning of October.

The spring generation of flies lay their eggs mostly in June in the leaves of docks and allied species. The larvae which hatch feed on the leaves eating irregular holes until fully grown, when they leave their host to pupate in the pithy stems of various plants. The second generation also lay their eggs on docks and allied plants; in August, and usually when fully fed at the end of September or early October, they migrate to the pithy stems of various plants or, as shown above, bore into the fruit of apples to hibernate and then to pupate in the spring.

In America, Newcomer says: "there are four generations which overlap and become somewhat confused."

Egg. The egg is kidney-shaped about 0·8 mm. by 0·6 mm. and white in colour.

Larvae. At first the larva is light in colour with the alimentary canal showing through. Later on the dorsum becomes bluish green with an almost black colour on the tops of the wrinkles, and the rest of the body of a dirty yellow colour. At the last moult the dorsum becomes apple green in colour with the sides shading from light green at the sides to yellow on the sternum.

Larva Found in Apples. (See fig. 2.)

About half an inch or less in length (specimens found October 4th, 1923, on docks measured $\frac{11}{16}$th of an inch).

Colour. Dorsum to line of spiracles apple green, sides of sternum paler shading from very light green at the sides to yellowish green on the sternum.

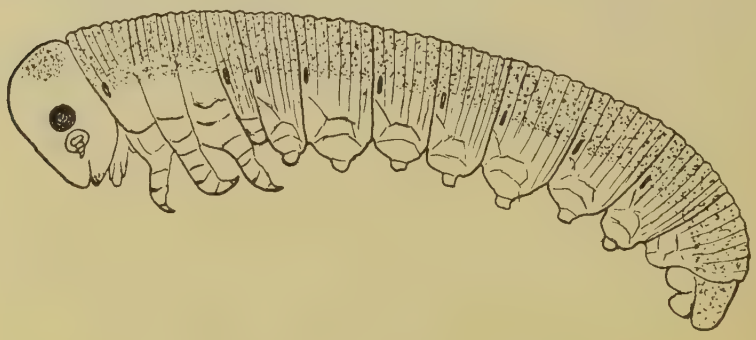

Fig. 2. Larva of *Ametastegia glabrata* from an attacked apple.

Legs. Five segments yellowish, dark brown line across the apex of the middle and a less distinct line across the base of the segment. Brownish curved claw at apex, a few spines present.

Prolegs. Yellowish green; 8 pairs on abdominal segments 2–8 and the last abdominal segment.

Spiracles. Four times as long as broad. Black, surrounded by smooth patch of skin. Occur just at junction of the dark green with the lighter colour. Nine in number, on first thoracic segment and first eight abdominal. Length of thoracic spiracle 170μ by 35–39μ. Abdominal spiracle 102–119μ long.

Body. Cuticle much wrinkled and finely shagreened.

Head. Declined backward, very light shade of brown with dark olive patch on the apex not extending to first thoracic segment.

Eyes. Black, raised, with a black ring round them, situated in pale-coloured part of head.

Antennae. Just below the eyes with a broad basal segment and four small joints darker in colour.

Mandibles. Yellowish at base, with three large teeth dark brown in colour.

Pupa. At first bright green on the dorsal region, with the rest of the body, head, legs and antennae pale yellowish green. Eye large and reddish brown. Before the adult emerges the pupa becomes almost black.

Adult. As Cameron says, its reddish legs, black posterior tarsi and *coppery, violet* body distinguishes it from the other species. He says it is very common and universally distributed.

Experimental.

Experiments were carried out to show that the damage was due to these larvae, and for this purpose two larvae found feeding on docks in Norfolk were placed in a bell jar with four apples on September 23rd, 1923. At first the larvae fed on the dock leaves, but when these were dried up they began to bore into the apples. On September 28th they had made 8 holes, on October 3rd 13 holes and on October 9th they had made 16 holes and were both present in the apples.

Previous to this Miss Chawner succeeded in making the first brood bore into an apple. On August 2nd, 1923, she wrote as follows: "I succeeded in rearing 4 larvae from virgin eggs laid by the fly which you sent me. I experimented as follows: To one I gave pith, into which it bored. To two I gave pith and a sound young apple to choose between—both preferred the pith. To the remaining one I gave only a sound apple; it bored into it with perfect ease. I may add that all four larvae have produced male imagines as is customary with unfertilized eggs laid by this species."

Economics.

As the larvae of this pest feeds almost entirely on docks and polygonums and does not feed on the leaves of the apple, it is not likely to become a serious pest. In the orchard where the apples were injured docks were fairly plentiful in 1922; but were kept down in 1923 with the result that no damage was done and only a few larvae were found in the hedges. Even in orchards where host plants are growing the

larvae would probably be prevented from ascending the trees by suitable banding.

I am indebted to Mr J. W. Cowland for assisting me with this work.

SUMMARY.

The larva of the dock sawfly, *Ametastegia glabrata*, Fallén, which is a leaf feeder usually found on docks and polygonums, injured apples in East Norfolk by boring small holes into the flesh in which to pupate. They made from one to six holes in each fruit. They were kept in check by keeping the orchard clean.

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POTATO LEAF-ROLL AND DEGENERATION IN YIELD

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The now generally recognised economic importance of the 'virus' diseases of the potato is due, no doubt, to the belief that they are mainly responsible for the 'running out' or degeneration in yield, so noticeable in most potato growing districts when 'seed' is saved for planting in two or more successive seasons. At present, whilst there is ample evidence that virus diseases do reduce the yield to a considerable extent there is no sound evidence that degeneration may be due to other causes, such as senescence or enervating conditions of growth.

In the absence of definite proof that diseases of the virus type are due to the action of specific organisms, they must still be described in terms of the symptoms produced in infected plants. The usefulness of this method of segregating diseases is limited by the fact that both external conditions and varietal characteristics greatly modify the symptoms observed. It is, therefore, not yet possible to say whether diseases described as simple (as distinct from composite) in one country (16, 18), occur in another in which climate, soil characters, cultural operations and varieties grown, may be very different. These difficulties are less marked in the case of leaf-roll, for although the symptoms may vary considerably with the variety affected and to some extent with external conditions, there is little doubt, in most cases, as to the identity of the disease in its second year or secondary form. In this secondary form leaf-roll can usually be diagnosed with ease by the dwarfing of the plant accompanied by the development of a rigid habit and stiff, leathery, pale green, upwardly-rolled leaves. Frequently all leaves are affected but not uncommonly rolling only takes place in the lower leaves. Quanjer's primary symptoms (13) have rarely been observed with certainty in any variety commonly grown in N. Wales, and never in the variety Arran Comrade used in the present investigation. The development of colour in affected leaves and the persistence of the 'mother' tubers—although common—are not constant symptoms of leaf-roll. It is often stated (19)

that leaf-roll increases the proportion of 'seed' and 'chats' in the crop; that this is not invariably the case will be seen later. In the writer's opinion, both the occurrence of necrotic elements in the phloem and of excess starch in the leaves—as reported by Quanjer(13) and Murphy (9, 11) respectively—are reliable aids in diagnosing leaf-roll. No method for the diagnosis of leaf-roll in the seed-tuber has been published. This would greatly increase the possibility of controlling the disease, and that such an advance is not too much to hope for is shown by the considerable difference in dry matter and nitrogen content in tubers from rolled plants when compared with tubers from healthy plants grown under the same conditions; facts which have been repeatedly established in the course of work in progress by Mr W. McLean of this College, in collaboration with the writer.

Present Work. The work described below, on which the writer was engaged during the years 1921, '22 and '23, was concerned entirely with the economic aspect of leaf-roll in North Wales, and not with the aetiology of the disease. The variety used throughout was Arran Comrade and both diseased and healthy stocks were selected and sent to the writer by Mr A. D. Cotton, late Mycologist to the Ministry of Agriculture. Similar stocks were sent to other centres and the yields obtained in 1921 from both kinds of 'seed' were published by Cotton(6, 7).

During the present work, large differences in yield between healthy and rolled plants have been taken as a measure of the degree of infection. In arriving at conclusions, however, it has not been forgotten that other factors may influence the yield to a considerable extent; such factors, for instance, as origin of 'seed,' slight variations in methods of storage, time of planting or cultural operations, and differences in soil, have been eliminated as far as possible.

Some preliminary experiments in 1921 may be disposed of briefly.

(1) *Communicability of leaf-roll by grafting.* Infection was obtained by joining the halves of a diseased and a healthy tuber together, cementing the edges with grafting wax to prevent undue evaporation, and carefully excising the 'eyes' from the diseased half. The composite tuber produced diseased shoots from the originally healthy half, as did also the rolled-half control, whereas the healthy-half control produced a normally healthy plant. This confirms Quanjer's statement(14) as to communicability of the disease in this way.

(2) *No control of leaf-roll by immersing tuber in corrosive sublimate.* Forty tubers from diseased stock were immersed in 1/1000 mercuric chloride for an hour and a quarter; the solution being allowed to cool

from 37° C. They were then rinsed in tap-water, left overnight to dry and planted alongside untreated tubers. One or two plants were apparently healthy but no more than in the controls. Blodgett has since(2) tried the effect of hot water, as well as mercuric chloride but finds that in both cases all potatoes surviving the treatment were affected with leaf-roll.

(3) *Effect of cutting diseased tubers before planting.* The well-known fact that some varieties, *e.g.* Majestic, do not 'cut' well suggested an experiment to see if this also applied to leaf-roll tubers. Each of forty half-tubers planted produced a plant and the yield as compared with that from the same number of cut healthy tubers closely approximated to the results in other trials in which the tubers were not cut.

Loss in cropping power due to leaf-roll. An attempt has been made during the last three years to determine the loss of cropping power due to leaf-roll, and to ascertain whether the effects are cumulative under the conditions of N. Wales.

In all the results reported below comparisons are made between the yields of diseased and healthy stocks growing in adjacent rows.

1921. The average yield from 17 rows of leaf-roll plants was 32·1 lbs. per row, whereas 8 rows of healthy plants gave an average yield of 72·6 lbs. per row of the same length. If the yield of the healthy rows is taken to = 100, that of the diseased rows = 44·2; showing a loss in yield of 55·8 per cent.

1922. The average yield from 12 rows of the progeny from the 1921 leaf-roll plants was 48·9 lbs. per row and that from 6 rows of new Scotch 'seed' was 89·9 lbs. Again taking the latter yield as = 100, the yield from the diseased stock was 54·4, *i.e.* a loss of 45·6 per cent.

1923. One row each of new Scotch 'seed' and the progeny of the original diseased stock were planted in adjacent rows in different parts of the same field. As was expected, the yields varied in the different plots, doubtless owing to soil differences or other variable factors. The losses in four such plots were respectively 55·2, 46·6, 45·2 and 63·4 per cent.

It does not appear from these results that the effects of leaf-roll are cumulative under the conditions obtaining in N. Wales. This opinion is strengthened by a comparison of the losses in yield in stocks previously healthy but infected with leaf-roll in 1922 and grown in adjacent rows in the four plots mentioned above in 1923; these show losses respectively of 50, 44·8, 60·9 and 57·4 per cent.

Similar conditions apparently are found at Craibstone in the North

of Scotland, for in the variety Kerr's Pink the loss due to leaf-roll was 73·2 per cent. in 1920 and 73·9 per cent. in 1921 (20). In a letter to the present writer, Mr W. M. Findlay, of Craibstone, states that affected plants show a progressive loss in cropping power during the first year or two, after which the yield is either maintained or even improved as the plants become adapted to their changed conditions.

The opinion is so strongly held by pathologists that leaf-roll is cumulative in its effects that an attempt has been made to get definite evidence on this point. The only example the writer has been able to find is at Leeds, where, using the same stocks as at Bangor, losses of 39·7 and 60 per cent. were obtained in 1921 and 1922 respectively[1].

It should be observed that the increased loss at Leeds occurred in the year in which a decreased loss was recorded at Bangor. There is some evidence, therefore, that the disease becomes intensified in the progeny in some localities, *e.g.* Leeds, whereas in others a progressive deterioration or 'running out' is not likely to occur.

That cultural operations as well as climate may affect the yield from leaf-roll plants was shown in 1921 by leaving a row, in which healthy and diseased tubers were planted alternately, entirely uncultivated from planting to lifting time; the yield of the rolled stock showing a loss of 80·3 per cent. as compared with that from the healthy plants. Again, in 1923 two rows of healthy and diseased plants were left after 'earthing up' without further attention. Weeds over-ran the rows and a loss in yield of 70·1 per cent. was recorded.

Effect of leaf-roll on the size of tubers produced. It is usually accepted that leaf-roll plants produce only a small number of 'seed' size or small tubers in place of a normally healthy crop of tubers varying in size from 'ware' to 'chats' (19). To test this view the number of 'ware,' 'seed,' and 'chats,' was obtained in 1922 and 1923 from alternate rows of diseased and healthy plants. By ware and seed are to be understood tubers which do not pass through a $1\frac{1}{2}''$ and $1''$ square mesh respectively. In 1923 the average weight of 133 diseased ware tubers was = 4·8 ounces; that of 217 healthy ware being 4·4 oz. Similarly, the average weight of 176 diseased seed and of 517 healthy seed was 1·7 oz. and 1·8 oz. respectively.

The results obtained were as follows:

In 1922 the average of ten rows of rolled plants showed that seed-size and small tubers together represented 73·8 per cent. of the total

[1] The figures are based upon information received from Mr F. T. Bennett who carried out the trial at Leeds.

number of tubers produced; the figures for six rows of new Scotch stock and once-grown healthy being 74·0 and 72·4 per cent. respectively. Using the same method in 1923, the figures obtained were 60·6 per cent. for four rows of plants rolled in 1920, '21, '22, and '23; 70·3 per cent. for four rows of new healthy Scotch stock, and 56·4 per cent. for two rows of once-grown healthy plants.

In the same way the proportion of seed-size and small to the total *weight* of tubers produced was determined in 1921, '22, and '23; with the following results:

1921. Rolled plants = 78·4 per cent.; new Scotch = 75·3 per cent.

1922. Rolled plants = 46·8 per cent.; new Scotch = 49·7 per cent.; once-grown = 38·8 per cent.

1923. Rolled plants = 30 per cent.; new Scotch = 41·1 per cent.; once-grown = 29·9 per cent.

It appears from these results that it is an error to suppose leaf-roll increases the proportion of 'seed' and small tubers in the crop in this variety. On the other hand they support the general opinion amongst farmers in N. Wales that new Scotch seed usually gives a larger number of the smaller tubers than does once-grown seed. The results also suggest that weather conditions will greatly influence the size of tubers obtained, for whereas 1921 was very unsuitable for potato culture owing to the drought and heat, ample rain fell in the summers of 1922 and 1923 to allow of continued tuber growth.

Effect of leaf-roll on the total number of tubers produced. The reduction in the total number of tubers produced as a result of leaf-roll infection was ascertained in 1922 and 1923 by comparing the average yield per plant of diseased and new Scotch stock.

1922. Twelve rows of diseased stock gave averages of 9·4, 8·3, 7·0, 8·9, 8·5, 7·2, 7·2, 7·4, 8·7, 8·4, 8·4, and 6·3 per plant; an average throughout of 7·9 tubers per plant.

Six rows of new Scotch seed gave 16·4, 16·5, 16·0, 14·3, 13·2 and 13·6; an average of 15 tubers per plant. The reduction in total number was, therefore, 47·3 per cent. in 1922.

1923. Eight rows of diseased stock gave 6·4, 5·7, 4·6, 5·8, 8·3, 6·5, 5·9, and 6·6; an average of 6·2 tubers per plant.

Two rows of new Scotch seed growing amongst the above rows gave 18·6 and 13·2; an average of 15·9 tubers per plant. The reduction in total number was, therefore, 61 per cent. in 1923.

Transference of leaf-roll under field and garden conditions in 1921. With the object of determining the conditions under which transference of

leaf-roll takes place plants were exposed to different chances of infection in 1921 in the following way:

(*a*) A row of the original healthy 'seed' from Scotland was planted in a field alongside new and once-grown stocks of a large number of varieties. These plants were, therefore, exposed to the ordinary chances of infection under farm conditions.

(*b*) Two rows of the same healthy 'seed' as in (*a*) were planted between four rows of rolled plants. In this way each of the two rows was exposed to infection from one side, both above and below ground. This plot was laid down in triplicate.

(*c*) Two rows in which diseased and healthy sets, placed alternately one foot apart, were planted between diseased rows so that the healthy plants were exposed to infection from all four sides both above and below ground; this was duplicated.

(*d*) One row of healthy and diseased sets, placed alternately one foot apart, were planted between diseased rows. Large roofing 'slates' were driven into the ground to a depth of about 4″ below the mother tubers, with the object of preventing the intermingling of the roots of adjacent plants. The healthy plants were therefore exposed to infection from all four sides above ground, whereas below ground they were partially protected from infection from neighbouring plants in the row.

Seed was saved from each of these rows and planted in 1922 with the following results:

(*a*) *Field-grown in* 1921. Average of six rows = 101·3 lbs.; average number of tubers per plant = 17·3.

(*b*) *Exposed to infection from one side in* 1921. Average of two rows = 105·75 lbs.; average number of tubers per plant = 17·65.

(*c*) *Exposed to infection from all four sides in* 1921. Average of two rows = 54·25 lbs.; average number of tubers per plant = 7·8.

(*d*) *Exposed to infection from all four sides but roots of healthy plants partially isolated by 'slates.'* Average of two rows = 72·1 lbs.; average number of tubers per plant = 10·85.

(*e*) *Plants rolled in* 1920, '21, '22. Average of two rows = 52·1 lbs.; average number of tubers per plant = 8·85.

No aerial insects were seen feeding on the potatoes although a careful search was frequently made during the summer of 1921.

These results justify the conclusion that no infection occurred under the conditions of (*a*) and (*b*). In both cases the foliage in 1922 was apparently quite healthy.

In Plot (*c*) maximum infection appeared to have taken place for

the loss in yield was fully as great as in the stock known to have been diseased for three years.

In Plot (*d*) where the roots of healthy plants were partially isolated there was a reduction of only 29 per cent. as compared with the healthy (field-grown 1921) stock. This reduced loss cannot be explained on the ground that some plants escaped infection since all the progeny in 1922 produced plants which were distinctly rolled, although the disease was not so marked as in the case of plants rolled since 1920.

Transmission of leaf-roll only occurred between plants in the same row; the disease did not spread across the rows although the foliage was in close contact during a great part of the growing season. So far as the writer can see, the only explanation which covers the facts is the supposition that transmission took place through the soil. Since all efforts by previous workers to effect transference of leaf-roll or mosaic by mere contact of uninjured roots have failed, it is perhaps most probable that soil fauna were responsible for the transference through the soil; if this were so it might explain why transmission was readily effected through the loose-worked soil of the row and not across the consolidated soil between the rows.

Some positive results obtained by Quanjer in his earlier work (13) led him to believe that the 'virus' can exist saprophytically in the soil, but his later work has convinced him that this is an error (14, 15, 16)—thus bringing leaf-roll into line with accepted views on other virus diseases of plants. It appears to the writer that this has led to a general disbelief in soil *transmission*—a very different thing. Quanjer showed that in every case where the roots of healthy plants were isolated from diseased ones a healthy progeny resulted, whereas in those cases where the roots were not isolated the progeny was invariably diseased (14, 15). Aphides occur on the potato foliage at Wageningen and no precautions appear to have been taken to protect the plants against aphis attack, yet though the foliage was in close contact, no infection resulted so long as the roots were protected. A similar experiment in which the same conclusion was arrived at has been recorded by Murphy (8). Quanjer (14, 15) and Oortwijn Botjes (3) have explained certain obscure cases of infection as being due to transmission from volunteers or from tubers found at a depth of half a yard which produced no shoots but only tuber-bearing stolons. It is clear that the occurrence of the latter can have no significance unless the possibility of soil transmission is accepted.

Transference of leaf-roll under garden conditions in 1922. In 1922 six rows each of new healthy Scotch seed and of once-grown healthy seed

were grown in alternate rows with the original diseased stock. The disease was readily transferred from the leaf-roll rows to the next healthy ones for the progeny of the healthy rows planted in 1923 produced diseased plants and the loss in yield, in most cases, was as great as in the originally infected stock.

During the summer of 1922 the experimental plots were examined for potato aerial insects by the Entomologist at this College, Mr C. L. Walton, who collected the following species on the foliage:

Macrosiphum solanifolii (Ashmead), fairly common.

Aphis solanina (Passerini), a few only.

Chlorita sp., one specimen only.

Sminthurus luteus (*Bourletiella lutea*), a few only.

No potato insects were found in the field on the farm crop.

The conclusive evidence which has been brought forward during the last few years that aerial insects are capable of transmitting leaf-roll to healthy plants (4, 17) leaves one in no doubt that the greater spread of leaf-roll at Bangor in 1922 is to be correlated to some extent with the appearance of insects on the foliage.

Effect of leaf-roll on the plant during the year of infection. It has been shown that healthy plants, exposed in 1921 to infection from diseased plants alternating with them in the same row, were so heavily infected as to produce a crop in the *following* year only equal to that from plants known to have been diseased for three years. During the year of infection (1921), however, the yield was fully as good as that from seed in which no infection had occurred; the former yielding 95 lbs. as compared with 84 lbs. in the two nearest rows of the non-infected stock.

There appear to be three possible explanations of this result:

A. Infection took place through the foliage and the virus passed direct to the developing tubers. This implies that the virus, just extracted from the foliage of a diseased plant, was unable to produce any marked physiological disturbance in the healthy plant during its movement to the tubers, although the same virus in the following year prevented the normal functioning of the elements concerned with translocation of carbohydrates to such an extent that the crop was reduced by 55·8 per cent.

B. Infection took place as in A, but the amount of inoculum was too small to cause appreciable physiological disturbance in traversing the aerial parts of the plant. The effects produced in the following year could then only be explained on the assumption that some development of the virus took place in the tubers during storage. It is probable,

however, that if any considerable development occurred during storage no evidence of reduced infection would have been observed when the roots of healthy plants were partially protected from infection.

C. Infection took place through the soil so that possibly the aerial parts of the plants were not infected at all in 1921.

Of these three suggestions the last one appears to be the most probable.

Unfortunately no comparable results were obtained in 1922 when some aerial infection probably took place, for all healthy plants in the trials became infected as was shown in their progeny in 1923. The fact that the loss recorded in 1922 was 10 per cent. or so less than in 1921 *may*, however, be a measure of the degree of infection of the aerial parts of the healthy plants in 1922, rather than of the improvement in the yield from diseased stock. Admittedly, much work will be required to establish the validity or otherwise of this surmise.

Relation of leaf-roll to seed-potato production. So far as our knowledge goes at present seed-potatoes can (or should) only be produced either where no virus diseases exist, or if present, where they spread very slightly. No information is as yet available as to the loss caused by diseases of the mosaic-type, but the results here recorded show the serious effects of obtaining seed slightly affected in Scotland with leaf-roll in 1920.

There is reason to believe that in some localities in the Scottish lowlands potatoes degenerate perhaps as rapidly as in many parts of England, and in some years a high percentage of virus diseases has been recorded in new Scotch seed in N. Wales. It is unlikely that there is any valuable quality inherent in 'seed' of Scottish origin and absent in that obtained elsewhere, for it has been reported that the locality from which seed is obtained is only of importance in so far as it determines the amount of virus disease present in the progeny (12).

In the early literature (1, 5) on degeneration diseases in England insistence is frequently laid on the fact that potatoes from 'cold, mossy' soils or from moorland are not usually subject to 'curl'—a term which doubtless included the disease now known as leaf-roll. Seed from such districts was said to be as good as that from Scotland. In many districts adjoining hill-land in N. Wales it is customary for lowland farmers to secure 'seed' from farms at a higher elevation. Whilst engaged with Mr C. L. Walton in an investigation on the relation between the occurrence of potato insects and virus diseases many areas have been located in which seed of some variety has been saved for many years—in one

or two for upwards of 80 years—apparently without any considerable deterioration in yield, and certainly without any obvious symptoms of virus diseases on the foliage. Many of these districts are at no more than 300 feet altitude and one is at sea-level, but all are exposed districts and subject to strong sea winds: potato insects in such localities are very scarce.

The writer is of the opinion that a search throughout England and Wales will reveal many such potentially good seed-potato growing districts.

Grateful acknowledgment is due to Professor R. G. White both for help and criticism, and for the considerable facilities afforded the writer in carrying out this work on the College farm, Aber.

Summary and Conclusions.

1. The present communication summarises the first results of work now being carried out at the College farm, Aber, Bangor. It is to be regarded as a first progress report.

2. Quanjer's statement as to communicability of leaf-roll by grafting tubers is confirmed.

3. The unlikelihood that 'seed' sterilisation will be useful as a measure of control is indicated by the failure to effect any control by steeping infected 'seed' in 1 1000 mercuric chloride for an hour and a quarter.

4. Cutting diseased tubers before planting did not affect the yield.

5. The loss in yield due to leaf-roll was 55·8 per cent. in 1921, 45·6 per cent. in 1922 and 52·6 per cent. in 1923.

6. The effects of leaf-roll do not appear to be cumulative under the conditions at Bangor.

7. The proportion of seed-size and small tubers—as determined by relative weights and numbers—to total crop was not increased in the variety Arran Comrade as a result of infection with leaf-roll.

8. The reduction in total number of tubers produced by a leaf-roll crop was = 54·4 per cent. in 1922 and 61 per cent. in 1923.

9. The transference of leaf-roll to healthy plants at Bangor in 1921 and 1922 has been studied. Evidence of soil transmission in 1921 is submitted. In 1922 both aerial and soil transmission is believed to have taken place.

10. Maximum infection in 1921 did not affect the yield in that year.

11. The relation of leaf-roll to seed-potato production is discussed.

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THE TOXIC ACTION OF COAL GAS UPON PLANTS

II. THE EFFECT OF COAL GAS UPON CORK AND LENTICEL FORMATION

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(With 2 Text-figures.)

Introduction.

Summaries have recently been given by one of us(7) of the experimental work upon which the conclusion is based that certain toxic effects produced upon plants by traces of coal gas in the atmosphere can be attributed to the presence of unsaturated hydrocarbons. In the case of growing roots and the epicotyls of certain etiolated seedlings it was possible to show that the effect of these unsaturated hydrocarbons could be associated with certain definite structural alterations in a tissue, the endodermis, which depends for its proper functioning upon a deposit of unsaturated fatty acids in its walls at an early stage of its development. Gaseous compounds with unsaturated linkages seem to act by rendering these unsaturated acids more mobile within the walls of the plant, and instead of their retention at the level of the endodermis they migrate towards the surface. Further observation of the phenomena associated with gas poisoning has only tended to confirm this general conclusion, whilst at the same time it suggests that the experimenter is thus provided with a new and valuable means of estimating the significance of the presence of such unsaturated fatty acids within the plant. Hansteen Cranner(3) has recently provided a very considerable amount of experimental evidence that all normal parenchymatous tissues may be expected to include as invariable constituents of their walls, certainly fatty acids, and possibly even phosphatides. It would seem a natural corollary that fatty acids should also form a normal constituent of the wall of meristematic tissues and considerable evidence for this has recently been obtained (Tupper-Carey and Priestley(13)), the iodine number of some of the fatty substance derived from the wall showing further that some of these constituents are certainly unsaturated. As previously suggested,

these unsaturated fats may partly be held in the wall as the result of a reversible chemical reaction in which the fatty acid takes part by its unsaturated—CH = CH—linkage, thus retaining its acid properties unaltered. In the presence of a gaseous unsaturated compound such as ethylene substitution of the ethylene linkage for the unsaturated acid renders the latter much more mobile, with its consequent migration, along with the sap stream in the walls, towards the outer surface of the tissue. Whether this explanation proves correct or not, it is hoped to show in this and later papers that the greater mobility of the fatty acids in the wall, in the presence of the unsaturated compounds contained in coal gas, is a phenomenon that permits of ready experimental demonstration, and that this phenomenon plays a very important rôle in most of the toxic effects produced by traces of coal gas upon the plant. In the present paper the effect of coal gas upon the formation of cork tissues is particularly investigated from this standpoint; in later papers it will be shown that similarly the remarkable effects of coal gas upon leaf and flower fall and in the production of epinastic curvature of leaves are associated with the greater mobility of fatty substances in the walls of the plant.

Movements of Unsaturated Fatty Acids in Meristematic Tissues.

In a previous paper (7) the abnormal curvature and swellings produced in roots and etiolated seedlings were dealt with and these phenomena associated with the incomplete formation of the primary endodermis usually present in these tissues, the unsaturated fatty acids instead of remaining in a strictly localised area in the endodermis diffusing outward and being found ultimately on other walls, even at the surface in the root sometimes. As a result the Casparian strip essential to the normal functioning of a primary endodermis, fails to form in some or all of the endodermal walls. Further experiment has shown us many cases of this effect but has also led us to realise that this failure of the Casparian strip must be considered as a secondary effect consequent upon the increased mobility of the unsaturated fatty acids within the walls of the meristematic tissue prior to the formation of the endodermis. As a result of the more rapid diffusion of these fatty substances from the meristem wall, this wall, especially in the etiolated stem, becomes distinctly more accessible to the aqueous sap by which nutritive material reaches the protoplast of the meristem. The result is seen in a more rapid growth of some of the meristematic cells and notably a more rapid vacuolation and extension in size as the result of the freer access of water

to them. Two examples may be cited in which this effect has been clearly distinguished from the more secondary result that, owing to this migration of the fatty acids, the primary endodermis is not so complete as usual.

The etiolated seedlings of lentil (*Lens esculenta* Moench) were under observation as Coupin(1) had recently described them as taking up a horizontal position in relation to gravity. Under examination no trace of such an effect was obtained, the stems growing perfectly erect as those of other etiolated seedlings. History therefore seemed to be repeating itself and Coupin's observations might be due to a trace of coal gas or other impurity in the air such as earlier led Neljubow(5, 6) and the other German workers to the first thorough examination of the impurities in laboratory air which affected their experiments upon tropisms. Etiolated lentils were therefore grown in the presence of traces of coal gas and the shoots rapidly showed the marked horizontal direction of growth described by Coupin. Furthermore, swellings were visible upon the narrow etiolated shoots and these upon anatomical investigation proved to be developed one or two inches above the level at which the endodermis had as yet differentiated. In the case of the broad bean or pea the swollen region in a young seedling usually corresponds with the region where an endodermal break can already be found, but if older seedlings are experimented with it is also possible occasionally to find the swelling developing at levels higher than that at which the Casparian strip can be detected.

The second line of evidence as to the importance of the primary effect upon the mobility of fatty acids on the walls, as distinct from the effect in preventing endodermis formation, is supplied by a study of the effect of traces of coal gas upon etiolated seedlings of *Phaseolus multiflorus* Willd. as no primary endodermis is present in the etiolated epicotyl of this plant (Priestley and Ewing(9)).

Here again, however, traces of coal gas or of ethylene produce a marked shortening of the growth of the epicotyl together with a swelling of the shoot, though this may not be so markedly localised as in stems where it is associated with a structural break in the endodermis. The effect of traces of coal gas upon the etiolated shoots and roots of growing plants must therefore be traced primarily to the effect of the gaseous unsaturated hydrocarbons present, upon the mobility of the unsaturated acids in the developing walls of meristematic and differentiating tissues, one effect frequently associated with this being the partial or complete disappearance of the Casparian strip of the primary endodermis. The fact that stems growing in the light show no such effect would seem to

mean that one effect of the light is to cause a rapid mobilisation of these unsaturated acids so that any subsequent further effect by the addition of traces of unsaturated hydrocarbons is rendered impossible. This effect of the light is in accordance with the difficulty in diffusion through the tissues of the apical meristem in the etiolated shoot which experiment has shown to exist, as compared with the ready diffusion along the walls of the green shoot in light (Priestley and Ewing(9), *loc. cit.* p. 32).

Cork Formation from a Meristem.

Before describing experiments upon the effect of coal gas upon cork formation, it will facilitate an explanation of these results if a brief account is first given of the developmental sequence of events in cork formation in a stem (Priestley and Woffenden(11)). The experiments subsequently described have all been carried out upon *Sambucus nigra* L., though many other plants have been occasionally used with concordant results. Events in cork formation can be similarly described for this one plant and thus precision given to the details. In general the essential points are common to all cases of normal cork formation in the stem.

In the young green twig the epidermis is covered with a cuticle, the only openings in which are the stomata; these occur all over the surface but are more numerous just below the node. Quite early in development, within two or three internodes of the apex, the substomatal air cavity shows an accumulation of fatty substance all over its floor and side, so that evaporation from the walls of the tissues bordering this air cavity must be considerably diminished in amount. It appears to be associated with this fact that a cork phellogen arises below a stoma long before it appears anywhere else upon the surface of the stem(11).

This phellogen cuts off regular tissue to the outside which gradually raises the floor of the substomatal cavity until the stoma is replaced by a lenticel, which at first appears as a pale coloured pustule on the surface of the internode, rapidly browning in colour as the cells outside the cork tissue dry up. The cork phellogen thus active below the stoma commences its activity in the centre of the substomatal cavity, spreading relatively slowly to the margin of the base of the lenticel; no further cork phellogen appears for some time, so that in the early summer, all the internodes from near the top to the very base of the current year's shoot are covered with lenticels in various stages of development. Later in the year, towards the end of July in Leeds in 1922, a cork phellogen arises throughout the surface of the stem, just below the epidermis, and so forms a continuous sheet of phellogen between the lenticels.

This new phellogen forms as a continuous cylinder, from the base upwards. Its passage up the stem can be traced by the colour change at the surface of the stem from green to silver grey. This change occurs following the first formation of cork cells from the phellogen, when air spaces appear between the epidermis and this new tissue beneath and modify the refraction and reflection of light from the cortical tissue.

No adequate explanation is known to us for this rapid formation of cork phellogen from the base of the shoot upward at this season of the year and the subject certainly seems to require investigation.

Whenever a cork phellogen becomes active, whether at the base of a lenticel or beneath the epidermis, the subsequent events seem to follow the same course. The cells of the phellogen are of the usual meristematic type, densely packed with protoplasm, with prominent nucleus and free from vacuoles (Priestley and Pearsall(10)).

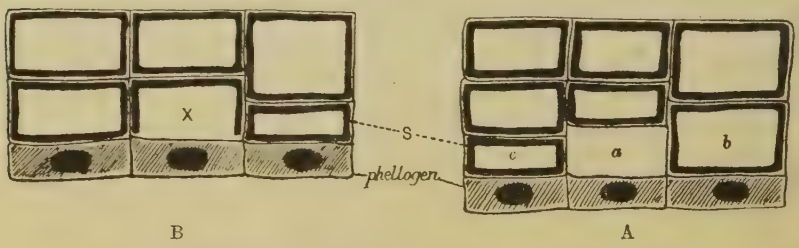

Fig. 1. Diagrammatic representation of cork cells cut off from phellogen. For description see text.

The wall gives no reaction for cellulose with chloriodide of zinc until after previous boiling with strong potash or prolonged treatment with Eau de Javelle. In this respect it behaves like other meristem walls (Tupper-Carey and Priestley(13)) and provisionally may be assumed to be a complex containing at least protein, cellulose, fatty acid and pectin. As the cells are cut off to the outside by this meristem they rapidly differentiate, the wall separates into two lamellae, an outer (middle) lamella, containing pectin and fatty acid, and an inner layer with a cellulose basis. At the same time large quantities of fatty acid are being liberated within the protoplast, containing, to judge from their reaction with osmic acid, considerable quantities of unsaturated linkages. These diffuse to the surface of the protoplast and there diffuse into and impregnate the two lamellae of the wall. As a result of the impregnation of the middle lamellae the cork tissue becomes very resistant to the normal macerating agents (acids followed by weak alkali or ammonium

oxalate) which depend upon their power of forming free pectic and fatty acids and then removing these acids as soluble salts. The unsaturated acid impregnating the lamella oxidises and condenses to a form which resists the action of strong acids (unless oxidising agents are present) and is also stable to weak alkalis. Most of this acid is however deposited in and upon the original cellulose lamella, and as it there undergoes oxidation and condensation forms the characteristic suberin lamella (Priestley(8)). A succession of cells are thus cut off to the outside by the phellogen and undergo this process of differentiation, the contents being ultimately either deposited on the wall as the suberin lamella (*S* of text-fig. 1) and its cellulose basis and inner lining or left in the cell as granular débris of no further importance.

As a result of the fact that the suberin lamella is formed from fatty substances released at the surface of the protoplast, the lamella forms simultaneously around the cell. Thus close examination will show that a cell such as *a* in text-fig. 1A has not yet commenced to deposit its suberin lamella and the first superficial appearance of three-sided suberisation is due to its position amongst cells (as *a*, *b* and *c* in text-fig.) already suberised. Close examination will show that such a cell as *X* in text-fig. 1B with a suberin lamella on three walls, never occurs during cork formation. It is now possible to discuss the effect upon this process of cork formation in the elder stem of the presence of coal gas with its gaseous unsaturated hydrocarbons.

Experiments with Coal Gas.

The experiments were carried out upon elder plants growing in the open, the gas supply being led out from a neighbouring laboratory (Leeds coal gas contains about 2 per cent. ethylene) and then divided into six streams by T joints, such streams passing through a washbottle and so to a tube fixed upon an elder stem. The gas supply was regulated by screw clips upon the rubber junctions and so arranged that a slow supply was delivered constantly during the period of each experiment. No attempt was made to work with any definite concentration of coal gas around the stems. The tubing around the gassed stem was about one inch in diameter, the leaves being cut down, except the youngest ones, to admit its insertion; the tube was closed with a split cork at either end, the gas being led in through a tube in the lower cork and allowed to escape freely through a hole in the upper cork. No special precautions were taken to make the tubes air-tight; control tubes of the same diameter were always placed at similar positions on other stems of the same plant

and air was allowed to circulate through these. The experiments were all carried out in the period from July 1st to August 25th, 1922, the stems being examined after from five to nine days' confinement within the tube. When the younger internodes alone were under treatment, no leaves were cut off and the terminal shoot was just packed with cotton wool as it emerged from the top of the tube. When it was desired to compare the effect of gas upon the lower internode without removing the leaves, the shoots were enclosed within balloons of oiled silk, closed by corks at either end. These experiments require no further special

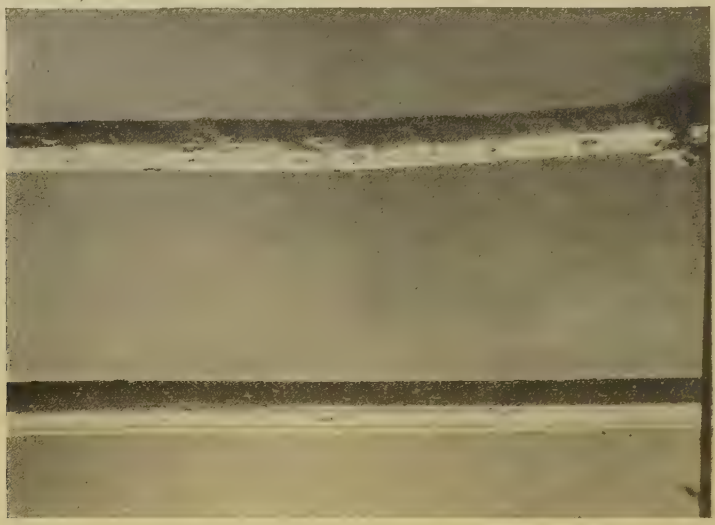

Fig. 2. Photo of elder twigs. A, exposed to coal gas; B, normal.

mention until leaf fall is discussed, as the effects of coal gas upon cork formation were unaffected by the removal of the leaves.

The result of the treatment with coal gas varied with the age of the internodes; three distinct types can be distinguished.

(i) Youngest internodes. When the apex of the shoot was exposed to the gas it began to droop within a few hours, later turning brown and withering. The stem immediately below the gassed nodes was nipped and brown and the stomata upon the gassed internode seemed to be sunk in little brown patches.

(ii) In tubes enclosing the internodes just below the apex and in any internode as far down as the fifth node before July 24th (1922), the

effects of gassing were noticeable at the base of the petiole and the lenticels. The leaves had been removed, leaving from $\frac{1}{4}$ to $\frac{1}{2}$ inch of petiole; almost invariably these dropped off within a few days, leaving a white spongy tissue covering the leaf-scar. The effect upon the lenticels varied with their age. The younger lenticels showed an eruption of white proliferated tissue in their centre, surrounded by a brown margin, the older ones showed a brown centre pushed up upon a white rim of proliferating tissue.

(iii) In the case of all stems gassed after July 24th no effect was produced upon the lenticels of the lower internodes but gradually the stem surface between the lenticels became swollen and discoloured (text-fig. 2); this appearance always showed first at the base of the gassed region, spreading up the stem, and frequently travelling three inches within 24 hours. After July 24th the effect was always obtained until towards the end of August, then the colour of the stem showed that cork formation had already occurred close up to the youngest internodes and the experiments were stopped as the coal gas was now without effect on any but these youngest internodes.

The control stems enclosed within tubes, showed that the striking effects produced in these experiments could not be ascribed to the moister atmosphere within the tube; in these stems the only effect produced was an occasional indication of proliferated tissue on the lower side of the base of the cut petiole after the tubes had enclosed the stems for two or three weeks. Only in one case did this proliferation cause abscission of the remaining part of the petiole and then after 23 days in the tube whilst the coal gas experiments were all examined after a much shorter period.

The connection of the effect with the age of the internode suggests that the effect is only produced at certain stages of development. In the youngest part of the twig the effect seems to be mainly produced in the region of the stomata. Sections showed the brown discolouration to be due to the presence of dead disorganised cells, the nipped regions below the node seem to be due to the great loss of turgidity in this region where the stomata are most numerous. This particular effect has not been investigated further at present, the main object of the present investigation being the effect of the gas upon cork formation.

The effects upon the lenticel show the first example of the connection of gas poisoning with cork formation and show clearly that the effect is produced at a certain stage of the phellogen's activity. In the young lenticels the phellogen in the centre of the substomatal cavity is in the

right stage and a mass of proliferated tissue appears in the centre of the lenticel. In an older stage, the cork in the centre of the lenticel is too far advanced to be affected and is simply carried up as a brown plug upon the proliferating cells resulting from the effect of the gas upon the activity of the phellogen near the margin of the lenticel.

Sections show that the proliferating cells are the cells cut off to the outside of the phellogen, which are practically completely unsuberised although on staining with Sudan III irregular accumulations of fat may be found within them.

Similarly when the lenticels are too old to be affected and the stem surface between is swollen, sections show that the epidermis in this swollen region is forced up by the large, proliferated, unsuberised cells, formed to the outside by the activity of the sub-epidermal cork phellogen. It is obvious that the normal differentiation of these cells is greatly modified when it has to take place in the presence of coal gas and that the main factor is again the inability of the unsaturated fats to deposit in the wall in the presence of the unsaturated hydrocarbons in the coal gas. This is further supported by the observation that whilst osmic acid shows very little unsaturated fat in these cells, if a strip of the epidermis be removed and the osmic acid applied to the inner surface, an instantaneous and very deep black reduction occurs, whilst if the epidermis be taken from the normal stem and a similar test applied, no reduction of the osmic acid is noted.

Evidently the unsaturated substances as they accumulate at the protoplast surface in the differentiating cork cells are no longer held upon the wall in the presence of the coal gas and so accumulate on the inner surface of the epidermal layer.

If the gassed and swollen stems are allowed to remain in normal air for some time, subsequent examination with Sudan III will show that the proliferated cells have gradually suberised although they are difficult to stain, the lamella being very thin and irregular.

It is apparently only those cells which are in a certain stage of differentiation when exposed to the coal gas in which distension takes place without suberisation, and if the phellogen has been active for some time before being exposed to the coal gas, outside the proliferated cells may be found not only unextended suberised cells but younger cells not yet suberised which have not undergone extension.

Discussion.

Earlier work upon the effect of coal gas upon plants does not always provide sufficient anatomical data for exact comparison, but there can be little doubt that where these observers record effects upon the bark of woody plants, their results admit of explanation in the light of the experiments described above, and in every case are due to the cells arising from the cork phellogen originally proliferating and failing to suberise.

Doubt(2), studying the effects produced by coal gas upon the root system of young trees, notes that the underground portion of the stems frequently become soft and swollen, longitudinal splits appearing in the bark; the effects were very marked with apple, pear, ash and *Hibiscus*, less striking with *Sambucus*, *Grevillea* and cottonwood. In *Sambucus* and *Hibiscus* she reports the development of soft spongy tissues upon the lenticels.

Harvey and Rose(4) also noted that in woody plants the increase in diameter of the roots and the bases of the stems was mainly due to the rapid cell division of the phellogen and the elongation of the cells thus derived from this layer. They also noted proliferation at the lenticels upon the basal regions of the stems growing in the ground and thus exposed to the gas.

This proliferation has also been noted by Stone(12) when growing willow shoots in water contaminated with coal gas; as a result, in some cases there was a readier root formation from these shoots than from those in ordinary water, presumably because more water was absorbed through the proliferated and less suberised tissue of the lenticels.

Evidently these effects are all of the same type and in a growing root or stem system, which is clothed with a cork layer at a certain stage of development, some portion of the plant's surface will be susceptible to the toxic action of the impurities in the coal gas so long as growth is still proceeding. It is extremely unlikely that the contamination of the atmosphere with coal gas will ever be sufficient to make this effect of practical importance in the case of stem growing in air, even under greenhouse conditions, but toxic effects may undoubtedly result from leakages of coal gas around a root system, if the normal protection of this root system and of the basal portion of the stem is a cork layer. In this case some of the cork layer forming during the period of leakage will probably show these effects of proliferation and lack of suberisation and such a surface tissue would seem to invite the entry of pathogenic organisms.

Finally it may be pointed out that the abnormal tissues forming at the surface of plants in coal gas contaminated atmosphere, when the cork phellogen is active, is undoubtedly very suggestive in reference to the special tissue, described by Schenck as aerenchyma, which normally clothes some parts of the stem and root of marsh plants when they grow in stagnant water. Such water is frequently contaminated with hydrocarbons, some of them unsaturated.

Summary.

1. Further experiments upon the effect upon the plant of atmospheres contaminated with coal gas, lend support to the view that this effect is mainly produced as a result of the mobility of unsaturated fatty substances in the plant walls in the presence of unsaturated gaseous hydrocarbons present in the coal gas.

2. Unsaturated fatty acids appear to be normal constituents of the meristem wall and in the presence of these unsaturated gaseous hydrocarbons they migrate towards the plant surface leaving the meristem walls more permeable. As a result, premature vacuolation and extension of the cells of the meristem take place. A failure of the primary endodermis in root and etiolated stem, owing to the absence of the fat impregnated Casparian strip, is frequently associated with this greater mobility of the unsaturated fatty acids. The normal green stem is indifferent to traces of coal gas because the fatty substances leave the meristem walls and accumulate in the surface wall at a very early stage of development.

3. The development of the cork phellogen in the stem of *Sambucus* is briefly traced, and the effect of coal gas upon this stem at different developmental stages is described.

4. The effects described are best interpreted on the assumption that at a very early stage of their formation, the cork cells cut off from the phellogen are very susceptible to the presence of coal gas. At this stage these cells become distended with water, and the fatty acids diffusing from the protoplast, fail to remain in and on the walls so that no suberin lamella is formed.

5. These results are entirely in accordance with the effects of coal gas upon the differentiating cells of the apical meristem of etiolated stem or root and can be explained by the greater mobility of unsaturated fatty acids in the presence of the gaseous unsaturated hydrocarbons present in the coal gas.

6. The experimental results are also in accord with those of earlier investigators. They suggest that coal gas will not be toxic to cork enveloped tissues except in the case of leakage from buried gas mains around the root systems of the plant; entry of pathogenic organisms will then be facilitated by the proliferated, unsuberised tissue formed from the cork phellogen.

7. The proliferated tissue formed from the cork phellogen in these experiments with coal gas appears to be suggestive in connection with the aerenchyma formed upon plant surfaces immersed in stagnant water.

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FURTHER OBSERVATIONS ON THE PREVALENCE AND HABITS OF *OSCINELLA FRIT*, LINN.

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(With 3 Charts.)

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INTRODUCTORY REMARKS.

Many facts relating to the bionomics of the frit fly have been accumulated in recent years. The larvae live on cereals and grasses during the summer and on either grasses, volunteer cereal plants or late sown cereals during the winter. The flies emerge in maximum numbers in spring, mid-summer and late summer but the relation of one generation to another in the field has not been accurately determined. The nature of the damage caused by the larvae is notorious, as also is the fact that early sown cereals suffer less infestation (from the practical point of view) than those sown late; but as yet we have to confess to ignorance of the factors controlling the difference in effective infestation in the two cases. We are equally in the dark as to the relative values of the many varieties of oat from the standpoint of susceptibility to infestation and power of recovery and the effect of these factors on subsequent yield.

The problems which present themselves for immediate solution are therefore (1) whether age of shoot is correlated with any morphological or biochemical variations which may be factors limiting infestation and (2) to what degree varietal differences influence infestation and yield under similar environmental conditions. Before knowledge gained by

the solution of these problems can be applied in practice it is necessary to determine the variation in the field population throughout the year, the range of the maximum prevalence periods of the imago in the field from year to year and the relationship between maximum prevalence and maximum oviposition periods. Wild host plants, if heavily infested, may have considerable influence on the position of these maxima.

Data relating to the prevalence of the frit fly in the field have now been collected during the four consecutive years 1919 to 1922, which have shown wide variations in meteorological character. The observations made during 1919 and 1920 have been published (3) but are included in Chart I for comparison with the subsequent data. The interpretation of the first set of observations was difficult owing to the fact that the field data were apparently at variance with the experimental data and the more recent work has made it necessary to correct the views expressed in the previous publication (3).

Certain observations on the action of the larva on the host plant are also included.

A. The Prevalence of the Imago in the Field.

Method of Procedure. The observations were again made on the University Farm, Sandford-on-Thames, the method of procedure being identical with that of the previous years (3). It is admittedly a crude method of determining population, but it is difficult to devise a more efficient yet practical procedure. In 1921 flies were collected on area G (3, fig. 1), but as this field did not carry spring oats in 1922, it was then necessary to sweep in a field on the same farm about $\frac{1}{4}$ mile north-east of area G.

1. *Data obtained by Sweeping.*

In 1921 Scotch Victory oats were sown on Feb. 2, succeeding roots in 1920 and winter oats in 1919, while in 1922 the same variety, sown on March 17, followed crops of roots in 1920 and 1921. In 1921 the oats matured in the middle of July, while in 1922 ripening was very slow, sweeping being continued until the end of August. The crops covered several acres in each case.

The smoothed curves in Chart I represent the prevalence of frit fly during the four years 1919 to 1922. Each point on the curves indicates the mean, over a period of seven days[1], of the number of flies caught while making fifty sweeps with a net twelve inches in diameter, on one

[1] Seven day periods were taken in order to eliminate as far as possible variations due to unfavourable collecting conditions.

or more occasions during that period. These seven day periods are reckoned arbitrarily from the first day of operation in 1919, and between the same dates in each year. In this way 22, 55, 20 and 3 per cent. of the points on the curves represent the mean values obtained from four, three, two and one field collections respectively, during the four years. The abrupt cessation of the curves is due either to the removal of the crop for economic reasons, or to the fact that when the seed is mature it is impossible to collect flies by this method owing to the rapidity with which the oats choke the net. Minimum grass, mean air and sun maximum temperatures and also rainfall, are shown in Chart II[1]. The method of smoothing necessarily differed from that adopted for the field data, as it was essential to include data for each day between the last days of collection in consecutive periods.

2 (*a*). *Interpretation of the Prevalence Curve for* 1922.

The form of a prevalence curve derived from field data obtained from a cereal crop may be dependent on several factors such as (1) the number of generations in the cycle, (2) meteorological variations, (3) variation in susceptibility of host plant, (4) influence of wild host plants and (5) longevity of imago in the field. Meteorological variations, by altering the rate of development of the immature stages may cause variation in the periods occupied by the different generations and variations in the form of the curve. Variation in susceptibility of host plant may cause differences in extent of attack and movement of the period of maximum infestation. Wild host plants, to some extent, control the spring migration and by competition may affect the extent of oat infestation throughout the cycle. Longevity of the imago in the field will influence the form of the curve since maximum emergence and maximum prevalence periods will be separated by the longevity. If longevity is short, then emergence and prevalence curves will be nearly coincident.

As only the 1922 prevalence curve indicates the changes in population throughout a whole season it will be advantageous to consider this curve first and then compare the previous curves with it. In the first place there were no pronounced variations in the meteorological conditions during July and August to account for the maxima which were observed during these months and it is evident from our present knowledge of the bionomics of the fly that in this year the cycle was divided into three generations, distinguishable in the field about the periods ending June 13

[1] Meteorological data supplied by the Radcliffe Observatory, Oxford, by the courtesy of the late Dr Rambaut.

and August 8. During the first period (May) Generation III appeared on the oats after hibernation during the larval stage in grasses. This was an immigration curve and may or may not have been (1) coincident with the emergence curve and (2) independent of the growth of the crop. A prolonged spell of high mean air temperature in spring evidently favours either fly production or collection, a short spell of high temperature in the spring of 1920 failing to produce a similar result[1], but observations made while the crop is young, necessitating sweeping close to the soil, are of doubtful value in indicating population. During the second period (June July) the flies of Generation I emerged, the immature stages having fed on the young stems of oat and grass and the majority of these flies oviposited on the oat seed. During the third period (August) the flies of Generation II emerged, their larvae having been bred in the seed, late tillers or grasses. The prevalence curves of the years 1919 and 1922, during this third period, show very rapid changes of frit population on the oat crop. The curve here may be intermediate between the true emergence and the true prevalence curves and its form will be dependent on the relative attractiveness of cereal and grass. So late in the season, however, the oat crop will be unsuitable for oviposition and it is most probable therefore that the curve in this region approximates to the emergence curve, as emigration will be equivalent to short longevity in the field. The form of the curve at this season supports this view very strongly, there being very great disparity between the average number of flies present in the field during the periods ending Aug. 15 and Aug. 22, both in 1919 and 1922. Even if all the flies present during August 2–8 belonged to Generation II, the assumption that maximum emergence took place before maximum prevalence would imply that all the readings during August 9–15 were incorrect. As indicated in a previous paper(3) the development period decreases from 50 days in spring to 35 days in summer, which to some extent may explain the surge of Generation II in August. After August 29 the curve should no doubt fall much less rapidly, since flies may be taken in the field up to the middle of October(3, p. 108) but the collection of flies from oats becomes increasingly difficult as the seed matures. The very late individuals are probably the progeny of late members of Generation I, or perhaps early members of Generation II, in each case having fed on grasses in the larval state. It is obvious that the generations overlap considerably in the field.

[1] The prevalence of the fly on *Lolium italicum* and also on barley in 1922 is recorded on Chart I. These data were collected on the next farm by the courtesy of Mr A. Kerwood and show (1) that the curves are not crop curves and (2) that immigration is rapid.

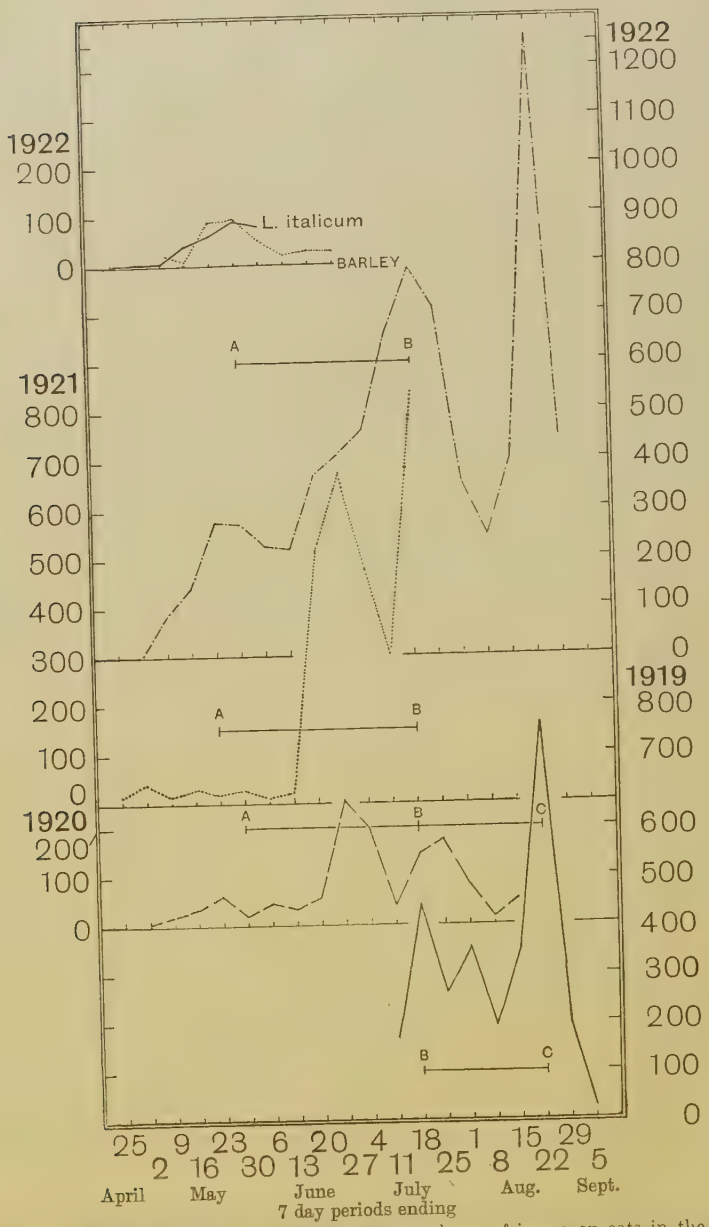

Chart I. Oscinella frit, Linn. Curves showing prevalence of imago on oats in the field, 1919–1922, and also on *L. italicum* and barley in spring 1922. A–B and B–C = average intervals in days required for the production of Generations I and II (determined experimentally) respectively.

Dates of sowing, 1919, May 2: 1920, Mar. 10: 1921, Feb. 2: 1922, Mar. 17.

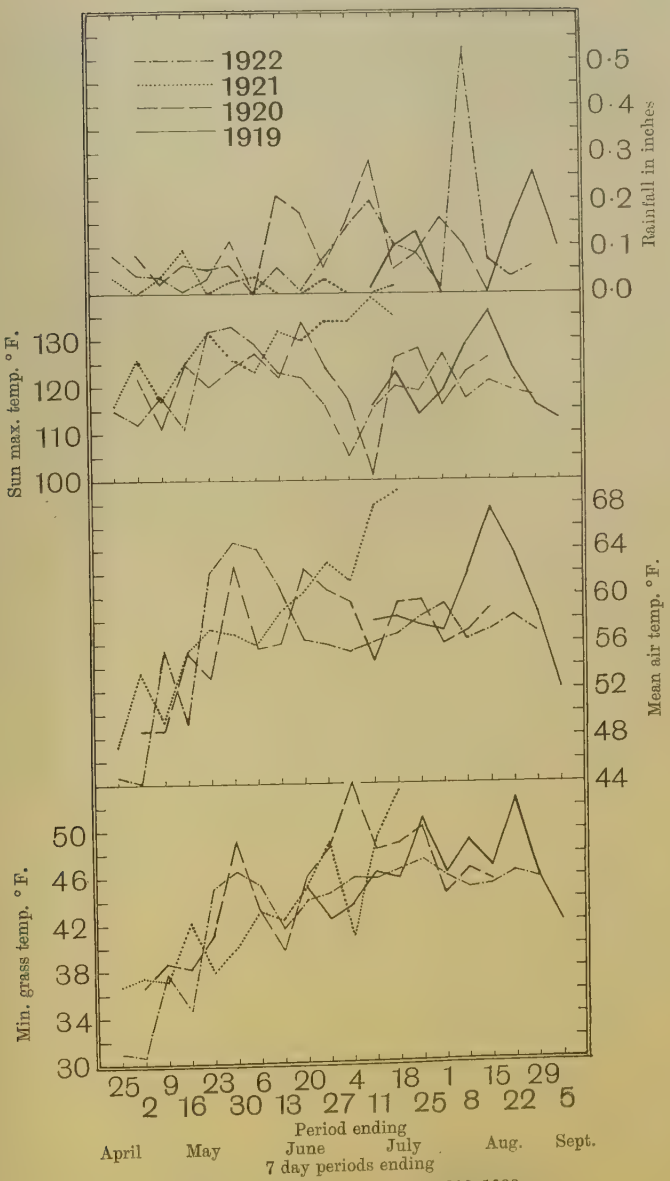

Chart II. Meteorological data, 1919–1922.

We may now consider experimental evidence collected during the four years 1919 to 1922 in relation to this interpretation of the curve. The results of outdoor breeding experiments are shown on Chart I under the different years, the periods A–B and B–C representing the mean number of days between the emergence of the consecutive generations, I from III and II from I respectively. In each case the parent flies were taken direct from the field in order that the oviposition periods in the cages and in the field might be comparable. To simplify comparison the points B are all placed in the period July 12–18, A and C being reckoned from July 15[1]. From these data it is clear that oviposition by Generation III at the end of May should result eventually in the appearance of Generation II in the third week in August and that this is strictly in accordance with the prevalence curve for 1922, in which year the prevalence maxima occurred about May 26, July 15 and August 19, *i.e.* at intervals of about 50 and 35 days respectively[2], these periods being in agreement with those obtained experimentally. Since the prevalence curve for Generation II appears to approximate closely to the emergence curve, the inference to be drawn from these data is that the periods about July 15 and May 26 were the periods of maximum emergence also for Generations I and III respectively, field longevity being short. The actual position of the period of maximum oviposition is undeterminable from these data, but it is known that the fly commences oviposition three to five days after emergence, thus the periods of maximum emergence and oviposition are probably closely approximate.

[1] Synopsis of experimental data, abstracted from previous publications [3, 4 and 5].

1919.	Grasses infected	23. vii. 19.	B–C = 35·5 days (51 flies).
1920.	Cereals infected	15. v. 20.	A–B = 50 „ (11 „).
	Oat panicles infected	14. vii. 20.	B–C = 33·4 „ (3 „).
1921.	Grasses infected	18. v. 21.	A–B = 58 „ (55 „).
1922.	Oats infected	16. v. 22.	A–B = 47·7 „ (22 „).

In the case of grasses sown April 20, 1922, and examined June 11, 1922, only 34·5 per cent. of the larvae had pupated by the latter date [5].

[2] The dates on which maximum collections were made in the field were, in order of the years 1919 to 1922; in May, —, 22, 13 and 24 equal, 23: in July, 17, 19, 18 and 12: in Aug. 20, —, —, and 21. In years when conditions were good for collection, these maximum figures were far above the next highest figures, as shown in the following table, where the lower of the two highest readings in the period is expressed as a percentage of the maximum.

	May to June 13	June 14 to Aug. 8	Aug. 9 onwards
1919	—	42·5	47·7
1920	94·9	79·8	—
1921	74·6	47·6	—
1922	51·7	68·4	74·0

On examining the temperatures[1] during the periods A–B and B–C it was found that excepting minimum grass temperature they were all lower in the second period than in the first, although the second period was 15 days shorter than the first. It would appear therefore that temperature is not the only controlling factor, but that the length of the maturation period may be dependent also on either qualitative or quantitative variations in the food supplied by the host plant or even on periodicity in the cycle. These are problems amenable to experiment which await solution. As indicated in Section B, the larva almost invariably attacks at the point where sap is likely to be most abundant. Baumberger(1) has demonstrated that in the case of *Drosophila* larval longevity is determined by the nitrogen supply and the fact that in this case the fly transfers its activities from stem to seed suggests that the availability of nitrogen may be the limiting factor when temperature is more or less a constant[2].

2(*b*). *Prevalence Curves during* 1919 *to* 1921.

It now remains to ascertain whether the above interpretation will apply also to the changes observed in the field population during each of the years 1919 to 1921. By comparison of the curves shown in Chart I it will be seen that the minima of the periods ending June 13 and August 8 are in close agreement, that in all years except 1920 the July population reached a maximum during the period ending July 18[3], and that in 1919 and 1922 the numbers of Generation II reached a maximum during the period ending August 22. But in the period ending July 11, the curve for 1922 shows no minimum, those for 1921 and 1920 pronounced minima, while in 1919 the curve may or may not be normal. Thus the question naturally arises as to whether a minimum should occur normally during the period ending July 11.

The data obtained from the outdoor breeding experiments (Chart I) would lead one to expect much the same grouping of the different generations in each year, and particularly in the years 1920 and 1922. The larva is an internal feeder and its rate of growth will be determined

[1] Mean temperatures in 1922 in ° F.:

	May 23 to July 15 (A–B)	July 15 to Aug. 19 (B–C)
Min. grass	45·6	46·0
Min. shade	49·3	48·3
Mean air	59·2	56·0
Max. shade	67·2	65·8
Max. sun	122·0	120·0

[2] The grass experiment in 1919 (p. 60, note 1) does not negative this suggestion, as the temperature conditions were uncertain.

[3] In 1921, field observations ceased during this period owing to the removal of the crop. Also see footnote (2) p. 60.

mainly by the factors, availability of suitable food and temperature. Food in the form of either cereal or grass is always abundant, and as each type of host plant may be utilised by each of the generations(3) imaginal swarming at any rate within the limits of the third and first generations would appear to be determined mainly by temperature. Temperature will affect (*a*) the rate of maturation in winter and spring and consequently the period of maximum immigration of Generation III and (*b*) the rate of development of Generation I and thereby the position of the maximum emergence period of this generation.

Year 1919. In 1919 and 1922, the corresponding parts of the curves are almost identical. In 1919 sweeping was commenced during the period July 5–11 but although the mean population was small during this period it does not necessarily follow that Generation I was only commencing emergence at this date. The oats sown on May 2 would have been above ground about fifteen days on May 26 and certainly liable to infestation, maximum or otherwise. There seems to be no reason for assuming that Generation III failed to attack the crop at this date or that infestation was due mainly to late members of Generation III plus early members of Generation I taking advantage of maximum susceptibility. In the latter case both maxima should have appeared later in the year, as the mean air temperature for the period A–B was intermediate between the temperatures for the same periods in 1920 and 1922[1]. For the period B–C it was 6° F. higher than in 1922, but the increase was due to high temperatures towards the end of the period only (from August 8) when its effect would be comparatively slight, influencing the pupal stage only. In addition, in view of the 1920 and 1922 observations and the fact that the mean air temperatures were closely comparable, the period occupied by Generation I in 1919 was much too short for swarming to have commenced during July 5–11. As the maxima of August 16–22 and July 12–18 agree in 1919 and 1922, it follows that the spring maximum prevalence in 1919 occurred about May 26 again.

Year 1920. The mean air temperatures for the periods A–B and B–C for the two years 1920 and 1922 vary only by 2° F. the period B–C being cooler in 1922 than in 1920 and the period A–B *vice versâ*, while

[1] Mean air temperature in °F.:

	Prev. Sept. to April	May 23 to July 15 A–B	July 15 to Aug. 19 B–C
1919	43·5	58·4	62·2
1920	45·0	57·4	58·0
1921	46·3	61·6	68·7
1922	45·2	59·2	56·0

the crop conditions were very similar. There is then no reason to assume from temperature considerations that the minimum of July 5–11 in 1920 marks the end of a generation; it is due to the fact that the point is dependent on one field collection only, made when weather conditions were very adverse, the weather generally about these dates being cold, wet and windy. The facts that the period July 3–8 was recorded (3, p. 109) as being "too wet for sweeping" and that the weather was rough when sweepings were made in the adjacent periods seem to be very probable explanations of the whole of this depression. This being the case, the field and experimental observations taken in conjunction indicate that in 1920, as in 1922, the maximum prevalence of Generation III occurred about May 26. The slight increase in Generation I shown during the period ending June 20 is dependent on two divergent readings only and may actually have been more than is indicated in Chart I.

Year 1921. The records obtained in this year are of particular interest owing to the very exceptional meteorological conditions prevailing during the growing period, but they are however somewhat difficult to interpret. This year was characterised by an abnormal drought and by exceptional heat in July which resulted in the early sown oat crop ripening by the middle of July.

There are two possible interpretations of this curve, namely that (1) the minimum observed in July 5–11 may have been real in the cycle, *i.e.* the maxima may have represented the prevalence maxima of separate generations I and II or (2) the record of July 12–18 may have been, or may have been approaching, the maximum prevalence of Generation I only. In view of the exceptional season one would perhaps naturally conclude that the first theory is the more probable, particularly as mature flies were emerging in small numbers from the ears by the middle of July[1]. But the evidence is not in favour of this theory, although on the other hand there is some difficulty in determining definitely the cause of the July minimum from the facts available.

If the first theory interprets the curve correctly consideration of the experimental evidence in conjunction with the temperature data makes it necessary to assume that the maximum spring immigration occurred at the latest in the period ending May 9. If immigration were

[1] The first record of flies emerging from ears collected in the field was July 9. On July 18, 1921, the field was sampled in the quarter sections and in the centre, twenty panicles being collected at random in each position. After being rubbed out, 100 seeds of each sample were examined—infestation 19, 17, 18, 19 and 16 per cent. (centre). On Aug. 25, 1922, two samples showed infested seed to the extent of 58·7 and 52·8 per cent. respectively.

normal then the rate of development of Generation I must have been accelerated greatly.

Early Immigration. The mean air temperatures for the period September to April, during which Generation III is immature[1], for the years 1919 to 1922 were 43·5°, 45·0°, 46·3° and 45·2° F. respectively. These figures are in agreement with the early commencement of immigration in 1921, but it will be noted that the advancement is slight. The period of maximum spring prevalence will depend also on the temperature[2] prevailing during the pupal period, pupation occurring during March and April. For these months the mean air temperatures for 1920 to 1922, were 46·6°, 46·9° and 41·5° F. respectively[3].

Thus pupal development should have been much the same in 1920 and 1921 and delayed in 1922, thereby causing the postponement of the period of maximum prevalence in the latter year. But actually the 1920 and 1922 results are closely comparable, the temperature variations being therefore insufficient to affect the grouping of the generations. Thus the position that maximum immigration occurred about May 9 appears untenable, as otherwise one would have expected (*a*) to find flies in the field about the second week in April and (*b*) to have observed the surge of Generation I about May 17–23.

Clark, Adames and Margary(2) have shown as the result of phenological observations in 1921, that a season causing earliness in botanical phenomena does not necessarily cause correlated variation in insect cycles. The meadow-brown butterfly, the first appearance of which is recorded as normally occurring on June 12 in the Midlands, in this year appeared one day later (*in. litt.*). The longevity of the larva, which is the hibernating stage, was therefore normal in 1921.

Finally one may bring forward corroborative evidence in the shape of records[4] of the prevalence in 1921 and 1922 of an allied species with very similar habits, namely *Chlorops taeniopus* Mg., the larva of which mines in the stems of barley and couch grass (Chart III). In 1921 the fly appeared on the crop as soon as it showed above ground (May 20) and the spring generation disappeared on June 17 in 1921 and on June 20

[1] The longevity of the hibernating larval stage doubtless enables the different individuals to negative age differences to a great extent. In 1921 the mean air temperature for the development period of Generation II, July 15 to August 19 was 7·5° F. above the mean for the four years, but emergence was not correspondingly earlier in the spring of 1922.

[2] A study of the "effective temperatures" was confirmatory but afforded no additional information on either of these points.

[3] Mean minimum grass temperatures, March–April, 1920, 36°: 1921, 35°: 1922, 31° F.

[4] Data collected on a neighbouring farm by the courtesy of the owner, Mr A. Kerwood. In 1921 the barley was sown on May 10 and in 1922 on April 5.

in 1922, showing that there was in this case only slight advancement of fly development in the spring of 1921. The summer generations of flies appeared first on July 24 in 1921 and on July 30 in 1922, closely approximate dates considering the smallness of the infestation and the meteorological variations. Thus the maturation periods of this fly also were comparatively unaffected by the abnormal season of 1921.

The balance of evidence appears to be against the probability of undetected early immigration.

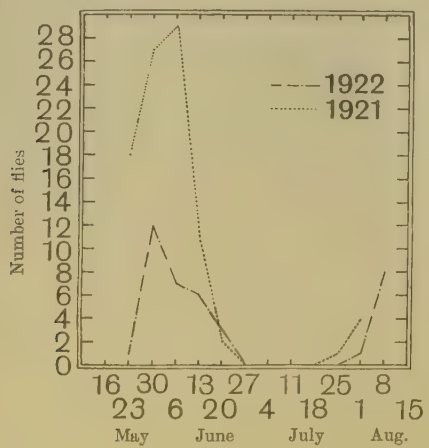

Chart III. Chlorops taeniopus, Mg. Curves (smoothed as in the case of *O. frit*) showing prevalence of imago on barley in the field, 1921 and 1922.

Accelerated Development. The alternative explanation that the apparent early swarming of Generation I was due to an increased rate of development caused by high temperature is excluded by the fact that the mean air temperature[1] for the period concerned, April 26 to June 27, in each of the years 1920 to 1922 was 55·8°, 56·6° and 56·9° F. respectively, the temperature differences being negligible compared with the 21 days difference in the appearance of the maxima in 1921 and 1922. The high mean air temperatures (above 70° F.) of this year occurred after July 8 only, too late to be effective in shortening the period for Generation I. In

[1] Maximum shade temperatures for the same periods, 1920 to 1922, 63·1°, 66·7° and 66·0° F. It should be noted that the surge of Generation I is comparable in all years. For the period May 23 to June 27, mean air temperatures 1920–1922 were 58·3, 58·6 and 60·6° F. respectively.

1921 the minimum of July 5–11 was apparently real in the field as the population decreased from June 28, seven collections being made between June 28 and July 11, a period favourable for collection. It is difficult to determine the cause of this decrease. It cannot be accounted for on the basis of non-activity, as the sun maximum temperatures were abnormally high during this time (see Chart II), while in 1922 very low temperatures in the period ending July 4 failed to produce a minimum. Minimum grass temperature however was very low (40·8° F.) for the period ending July 4, 1921, and it was only at the end of the succeeding period that recovery took place. This might check both pupal development and emergence and would explain the subsequent minimal prevalence, field longevity being short[1]. On the other hand, in May 1922, immigration increased rapidly from the 2nd onwards at a very low minimum temperature. The mere fact that the flies were present in large numbers when the grain was ripe would appear to be evidence in favour of the first theory. But if the majority of these flies belonged to Generation II, it follows that they must have been the progeny of Generation I swarming in maximum numbers during the period ending June 27. The improbability of Generation I having reached a maximum here has been indicated above. The fact that the fly was breeding in the seed in July does not necessarily imply that the majority of the flies collected in the middle of July belonged to Generation II. The oats were in flower at the beginning of June and these flowers would be sought as oviposition sites by late members of Generation III, the progeny of such individuals having sufficient time to mature by mid-July[2]. The grain infestation in 1921 was light compared with 1922 (footnote, p. 63), while the population was much the same in each year. If immigration were normal, then the July maximum was normal also, the flies being members of Generation I bred in late tillers. At the same time, additional immigration from wild host plants may have occurred.

[1] The correlation coefficient between prevalence over the period June 14 to July 18 and minimum grass temperature advanced one period is $+0{\cdot}68 \pm 0{\cdot}16$. Although the p.e. is high owing to the small number of mean values the high positive coefficient, while not very significant, would appear to support this view. In 1922 this minimum was absent and in May there was a single immigration maximum only. These facts are in agreement with the experimental evidence in both years and indicate that the minimum is not explicable on the assumption that the fly has double broods normally [3, p. 111]. Also as the spring immigration extends over a long period and as the fly is always present in the field except in winter, the curve should ascend regularly throughout the summer if more than one brood is normal.

[2] A minimum period of 41 days was observed during experimental breeding between the times of emergence of consecutive generations at this time of year [3, p. 110].

An interpretation based on variation in susceptibility to infestation, with consequent early infestation in 1921 seems to be precluded by the fact that the prevalence in August 1919 was comparable with that in August 1922.

The interpretation of the 1921 curve is admittedly a little uncertain, but from the data available it would appear that it represents the prevalence of Generation III and I and is therefore comparable with the other curves.

It may be concluded that the 1922 form of curve represents the normal summer prevalence undisturbed by adverse meteorological conditions.

3. *Constancy and Duration of Prevalence Periods.*

Viewed broadly these curves show a similitude which is remarkable considering the meteorological characters of the different years. The effects of these meteorological variations on the plants were more marked than in the case of the prevalence periods of the fly. The swarming of a new generation is definitely marked and strikingly constant in the different years, which means that the meteorological variations of the years 1919 to 1922 were not sufficiently diverse to move these points of the cycle out of the seven day periods.

Thus the field evidence shows that between May and August the frit fly has only three generations. In the imaginal stage Generation III extends from the period April 19–25 to the period June 7–13, with a maximum prevalence about May 26. Generation I extends from the period May 31–June 6 to the period August 9–15 with a maximum about July 15. Generation II extends from the period July 26–Aug. 1 to the period Sept. 6–12 with a maximum about Aug. 19. There may be a partial fourth generation between Generation II and Generation III (which hibernates in grass host plants) being the progeny of the early individuals of Generation II.

4. *The Relation of the Fly to its Host Plants.*

The immigration in spring of Generation III from wild grass hosts to the oat crop is independent of the state of the crop in regard to growth, and the period of maximum infestation seems to be more or less constant in time. This is important in relation to the yield of the plant as the main stems and early tillers may thereby escape attack in the case of early sown crops. The later tillers will of course always be liable to infection to a degree dependent on the time of their appearance in relation to the period of maximum oviposition. Thus the state of the crop

can only influence the extent of attack (from the point of view of yield) through variation in susceptibility. If increase in age causes a diminution in susceptibility (5), one would expect an early sown crop to produce a greater number of stems capable of shooting than a late sown crop. In the former case attack would be confined chiefly to tillers which would in any case have a low yield value, whereas in the latter case the main stems and first tillers would bear the brunt of the attack, while the extent of attack might be the same in each case. That the fly desires to oviposit on the oat rather than on suitable wild grasses[1] has been shown in a previous note (5) not to be true invariably. It appears more probable that the fly roves in search of oviposition quarters and that it will readily accept grasses in lieu of oats, if the former are more suitable for its purpose. If the form of the prevalence curve were dependent on susceptibility of host plant alone, one would have expected in 1922, when the oats were sown on March 17, that the emergence of Generation I would have been earlier than in the case of oats sown late as in 1919 (May 2). The fact that this is contrary to the field data obtained in these two years does not necessarily mean that variation in susceptibility of stem does not exist but that it may be obscured by the availability of a succession of tillers or grass stems suitable for breeding. In the case of the grain infestation a similar explanation will not suffice, since if the grain (which is formed in a short period) is beyond the stage desired for oviposition when the maximum prevalence occurs in July, the swarm of flies in August (Generation II) would be dependent on an earlier infestation by a smaller number of flies of Generation I. The maximum prevalence of Generation II should then be earlier in the case of an early flowering crop than in the case of a crop with a susceptible stage at or beyond the maximum prevalence period. Since the curves in 1919 and 1922 are identical at this period the inference is that prevalence in August is dependent on grasses as well as on oats.

Thus one is led to conclude that the fly is ready to utilise oat stems or oat grain if these are available at the right time, and if not, suitable wild or cultivated grasses; that the prevalence is therefore dependent on the total number of host plants present and not on oats alone; and that the nature of the curve is on the whole dependent more on wild than on cultivated host plants. While the growth of the oats in spring may or may not affect the extent of the attack on the stems yet it determines the yield, inasmuch as yield is dependent on the number of stems capable of shooting as well as on the extent of the attack on

[1] Grasses in which the fly has been bred experimentally are recorded in (3) and (4).

the grain. The attack on small or later tillers may maintain intensity without causing substantial loss in yield. If the crop could be protected from the fly in spring, the latter would find abundant food supplies in its wild host plants and swarming again in June and July, would be ready to attack the grain. Trap crops are therefore unlikely to be of much value in combating this pest, because of the ease with which the fly can adapt itself to any one of its numerous wild host plants and the enormous reservoir of flies which must be maintained in such plants.

B. The Action of the Larvae on the Host Plant.

Stem. In the field in spring, the majority of the eggs are found on the lower blades, living or dead, the number of eggs recorded per blade varying from one to thirteen, although numbers above three are rare. Later in the season eggs may be found on the upper blades, sometimes on the sheaths and even attached to the haulm near or just below the soil surface. When the panicles appear the eggs are laid inside the glumes. The attachment to the plant is very definite and doubtless aids the larva to free itself from the eggshell. On emergence the larva immediately seeks the cover of the sheath and penetrates to the region of the growing point, where the supply of sap is plentiful.

All types of entrance galleries have been observed. When the egg is deposited on the haulm near the ground, the entrance hole is visible and the gallery may be traced through the successive layers until the growing point is reached. More commonly, after gaining entrance, the larva cuts through the tissues in a horizontal spiral to the centre of the stem, thereby cutting off supplies from the youngest blades. In about 12–15 days external evidence of this attack is apparent owing to the consequent discoloration. In the former case there may be no external signs of attack or only slight flagging of the central leaf and this may lead to errors as large as 30 per cent. in estimating extent of attack[1], as the fly is present in the field from April to October. At the other extreme, the larva appears to work its way down from the blade between the sheaths and commence its attack well above the actual growing region. Whether it eventually includes the growing region seems to depend on the vigour of the shoot. This type of damage is usually confined to the

[1] On June 8, 1920, thirty plants were taken at random in the field. One or more larvae were found in 23 shoots but 29 per cent. of the latter showed no external sign of damage. In every case the larva had destroyed the growing region but the central leaf was killed only in those cases in which the larva had excavated a gallery round the base [see also (3) p. 122].

older stems, and may be considered abnormal[1]. In these cases the appearance of discoloration is of course dependent on the site chosen by the larva; panicle damage cannot be detected at this stage. The rapidly growing larva extends the gallery in the central shoot, the region of working almost invariably including the youngest tissues. If the stem is vigorous, the visible central shoot may suffer lateral damage only, in which case subsequent discoloration would be slight.

The range of shoots capable of utilisation by the larvae is very wide. Small tillers one-third of an inch in length and still enclosed in the sheaths have been found to contain larvae, even when the main stem has been free from attack. Presumably there is no question of preference here, the young tiller happening to be in the line of attack. Usually when the attacked stem is young, its growth is severely checked if not entirely inhibited and the side tillers are forced into growth abnormally. These in turn may be attacked before emergence from the sheaths if the principal stem does not afford the larva sufficient nutriment. Of the larger stems, namely those twelve inches or more in height, as many as one-fifth may be damaged beyond recovery[1]. When the attack is the result of oviposition by late members of Generation III or early members of Generation I, the developing panicles enclosed in the sheath are partially or wholly destroyed as shown by Roebuck (6).

The degree of destruction of the central leaf, the typical external sign of attack, depends partly on the method of entry and subsequent working of the larva and partly on the state of development of the plant.

Grain. It was noted when larvae were reared in captivity on fresh oat grains, that for the first three to five days they preferred to work along the groove and between the pericarp and the endosperm. In the few cases under observation, they subsequently extended their working into the endosperm in the region of the embryo. It is in this region that the conducting vessels enter the seed. In field samples this preliminary boring is most noticeable when the grain is either approaching or in the milk stage. When the attack occurs after fertilisation, but before growth is pronounced, the grain continues to receive food supplies until the vessels at the base are destroyed; dwarfed grain results and the endosperm may be entirely consumed by the larva. If the ovule is attacked

[1] During variety trials in 1923, the following data were obtained from oats sown on 18. iv. 23: number of stems examined = 2064; number of stems showing signs of injury exclusive of growing point = 40 or 1·95 per cent.; number of stems 12″ and over in height including blades = 473 or 23 per cent.; number of latter damaged = 102 or 21·6 per cent.

before or immediately after fertilisation, the larva destroys all parts of the flower which is consequently sterile[1].

Several seed samples were tested by measurement of their germinative capacity to ascertain whether the larval method of working in the grain invariably killed the embryo, different varieties, including awned varieties, being examined. From a sample of the variety "Abundance," with a germinative capacity of 72·6 per cent., a thousand grains were thrown into water to separate the sound from the damaged seed, which resulted in 55·1 per cent. sinking. The floating seeds were skimmed off and 150 seeds of each type were germinated under similar conditions. The germinative capacity of the heavy grain was 97·6 per cent., and of the light grain 41·8 per cent.[2] Examination of the seed which failed to germinate showed that of the heavy grain 2·4 per cent. of the seed had been slightly attacked, the embryonic region at the base alone being decayed, while of the floating grain 54 per cent. showed signs of attack in different degrees and 4·2 per cent. failed although apparently healthy. In a sample from "Excelsior" seed purchased for farm use (normal germinative capacity 93·2 per cent.), 15·5 per cent. of floating grain was obtained. The germinative capacities of the heavy and light sections were 97·4 per cent. and 69 per cent. respectively and in both cases the seed which failed showed decay at the base originated by frit attack. In neither case did any of the germinated seed show any sign of attack.

It would appear therefore that the larvae exhibit a pronounced tendency to attack those parts of the plant receiving an abundant supply of sap. The factor which determines the choice of site by the female, for the deposition of eggs, is at present unknown[3].

[1] It has been proved experimentally that a larva can reach maturity in this manner. The panicle of an oat plant was caged immediately after flowering and infected with a pair of flies. The plant bore 16 flowers, from which were bred five flies. Examination after the emergence of the latter showed that 11 grains were untouched, averaging 1·2 cm. in length; while of the five damaged grains, four measured 0·7, 0·7, 0·6, and 0·4 cm. respectively and one flower showed no development, even the anthers being destroyed.

Specimens of this type are encountered fairly commonly in field material, the empty puparia being usually present.

[2] The radicles of the germinated "Abundance" seed gave the following minimum, mean and maximum measurements in the same period: (1) heavy 0·1, 0·69, 1·4; (2) floating, 0·1, 0·4, and 1·1 cm. The "Excelsior" radicles averaged (1) 0·99 cm. and (2) 0·71 cm. The percentages of floating grain by weight were for "Abundance" 51 per cent. and for "Excelsior" 10·6 per cent. Thus in the latter case, where the original germinative capacity was high, 10 per cent. of the seed by weight was of poor value as seed either through frit attack or inherent weakness and could be utilised more profitably for other purposes.

[3] Chemotropic experiments, using ether extracts from stems of known age, gave negative results in 1923.

SUMMARY.

1. Observations on the prevalence of the imago of *Oscinella frit* in the field have been made during the period 1919 to 1922.

2. The annual cycle consists of three generations: Generation III swarms from the end of April to the middle of June, with a maximum about May 26; Generation I from the end of May to the middle of August, with a maximum about July 15; Generation II from the end of July to the beginning of September (or longer) with a maximum about August 19.

3. Although meteorological variations during the period 1919 to 1922 were apparently very diverse, they were not sufficiently diverse to affect the prevalence periods of the fly on the crop materially: the prevalence curves of the different years show a remarkable similarity. This may be due to the fact that the larva is an internal feeder.

4. As the periods of maximum prevalence are not displaced from year to year, it would appear that the fly population is determined by the total number of host plants and not by the cultivated plants alone.

5. The larva exhibits a strong tendency to attack those regions of the plant which are in receipt of abundant supplies of sap.

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THE INFLUENCE OF HYDROGEN-ION CONCENTRATION ON THE GROWTH OF CERTAIN BACTERIAL PLANT PARASITES AND SAPROPHYTES

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(With 3 Text-figures.)

In the course of a series of determinations of the points of maximum acid-agglutination for a number of species of bacteria, some of which were plant parasites, it was noticed that there seemed to be a distinct relationship between acid agglutinability and pathogenicity to plants. Although further work did not entirely confirm the view that tolerance of high hydrogen-ion concentrations is always a distinguishing characteristic of bacterial plant parasites, yet the important part which hydrogen-ion concentration probably plays in the defence of the plant cell against invading bacteria, seemed to make it of interest to find out how far it affects the growth and activity of different types of such bacteria.

It seemed possible that the acid limits of growth, and the hydrogen-ion concentrations producing agglutination would fall within the range of cell sap acidities in the case of non-parasitic species and above it in the case of pathogenic varieties. The following determinations were therefore carried out with 28 species, fourteen of which were parasites, and the others saprophytic organisms of common occurrence.

I. The determination of the points of maximum acid agglutination.
II. The determination of the acid limits of growth.
III. Determinations of the changes in hydrogen-ion concentration accompanying growth.

I. Determination of the Maximum Points of Acid Agglutination.

This series of tests had been originally begun in the hope that agglutination with acid would prove a ready means of identifying different species of bacteria. The points of maximum agglutination were not,

however, found to be specific, but, as stated above, there seemed to be a marked relationship in many cases between agglutinability and pathogenicity to plants. The series of determinations was therefore completed for 28 species representative of the following classes of organisms:

1. Fourteen plant parasites, most of which had been isolated in the laboratory. The cultures of *B. marginale* and *B. viridilividum* had been given by Miss N. Brown (6); the type here called "*Barkeri*" was a sub-culture of the organism causing pear blossom blight, isolated by Prof. Barker (2) while the *Aplanobacter Michiganense* strain was obtained from Dr Erwin Smith (19).

2. Four non-parasitic members of the *fluorescens* group, viz., *B. fl. liquefaciens*, *B. fl. non-liquefaciens* (*putidum*), *B. pyocyaneus* and *B. violaceus* (*janthinus*).

3. Five common sporing soil organisms.

4. *B. coli*, *B. prodigiosus*, *B. lactis aerogenes*, *B. faecalis alcaligenes*.

The fourteen species in the last three sections were all obtained from the National Collection of the Lister Institute.

The method used was that recommended by Michaelis (15) for the identification of typhoid and paratyphoid bacteria; but as his acetate solutions give only a short range of *p*H values, from 3·5–5·0, and the mixed series used by Bondorff (5) which included acetate, lactate, tartrate, and citrate mixtures, do not, as he admits, give concordant results, Sørensen's buffer mixtures of HCl and acid sodium citrate giving a range from *p*H 1·0 to *p*H 5·0 were employed. The mixtures of the two reagents were made up in the proportions 10 : 0, 9 : 1....0 : 10, giving *p*H values as indicated in Dr Walpole's chart of hydrogen-ion concentration data (22). All the strains of bacteria tested gave agglutination optima within the range of these citrate solutions except *B. mesentericus* which agglutinated in a mixture of acid sodium citrate and sodium hydroxide at *p*H = 5·4, and in a mixture of sodium acetate and HCl at 5·6.

The emulsions used were made from bouillon agar cultures of about 18 hours' growth; the growth was not washed off, but removed with a platinum loop, so that change of *p*H value due to admixture of water of condensation was avoided. Each of the agglutinating tubes received one part acid solution and three parts emulsion, these were incubated at 30° C. for four hours, or less, if agglutination was found to be beginning, and then allowed to stand at room temperature overnight. In some cases, when agglutination was very slow, the tubes were raised to a temperature of 37° C.

The following table gives the *p*H values at which maximum agglutination occurs in the citrate solutions in the case of the 30 species tested:

	Parasitic species	Non-parasitic species
*p*H = 1·2	Ps. phaseoli	B. pyocyaneus
	B. Barkeri	
	B. atrosepticus	
*p*H = 1·5	Aplanobacter michiganense	B. prodigiosus
	B. solaniolens	
*p*H = 2·0	B. Tolaasi	B. fl. liquefaciens
	B. aroideae	B. fl. non-liquefaciens
	B. campestre	B. violaceus
	B. marginale	B. coli communis
	B. viridilividum	B. lactis aerogenes
	B. solanisaprus	
	B. caratovorus	
*p*H = 3	B. lathyri	
	Ps. proteamaculans	
*p*H = 3·7	Ps. hyacinthi	B. coli communior
		B. faecalis alcaligenes
		B. subtilis
		B. vulgare
*p*H = 4·8–5·0		B. megatherium
		B. dendroides
		B. mycoides
*p*H = 5·4		B. mesentericus

The maximum agglutination points are not sufficiently well defined to be characteristic of individual species and therefore, as Bondorff concluded, the method is of very limited use as a means of identifying different kinds of bacteria. The majority of plant parasites showed marked resistance to the influence of acid; agglutination visible with a hand lens (magn. 10 diam.) began in these cases at about *p*H 3·0 and reached its maximum at *p*H 1·5–2·0. Above this point, at *p*H 1·4, flocculation did not take place or was very slight, and in the case of nine parasitic species tested, death of the organism occurred in less than half an hour.

The agglutination of the four non-parasitic members of the fluorescens group was similar in all respects. The sporing organisms on the other hand, with the exception of *B. subtilis*, are agglutinated by much lower hydrogen-ion concentrations, lying between the values *p*H 4·8 and *p*H 5·6.

The agglutinating points of coli-form organisms, as given by several investigators, usually lie between these two extremes, viz.:

Typhoid	*p*H 4·40	Michaelis (15); Beniasch (3)
Paratyphoid and paracoli	3·50–3·80	Michaelis; Bondorff (5)
B. coli (two strains)	2·96	Dreyer (9)
,,	2·6–3·0	Bondorff
B. faecalis alcaligenes	3·5	Beniasch

As will be shown later on there seems to be definite correlation between the resistance of an organism to acid agglutination and its power to produce acid or alkali from nitrogenous food material.

II. Determination of the Limits of Growth due to Hydrogen-ion Concentration.

In these and the following series of tests, Jardox peptone broth containing ·5 per cent. meat extract and 1 per cent. peptone was mainly used as culture medium; 2 per cent. peptone water was at first used, but the soil organisms gave little growth in it.

No salt was added to the broth, as the concentrated Jardox already contains 8–10 per cent. and growth at the higher degrees of acidity was found to be checked by the addition of a further amount. The presence of larger quantities of salt in the medium may account for the lower acid limits of growth given by Wolf and Shunk in the case of *B. caratovorus* and *B. campestre* (23); possibly also for the very low values given in the British Drug Houses list for *B. coli*, *B. pyocyaneus*, *B. faecalis alcaligenes* and *B. vulgare*.

The temperature of incubation of the cultures was always 19°–21° C. as this approximates to the natural temperatures at which these bacteria live.

All the *p*H values were determined colorimetrically, using the indicators recommended by Clark (7). About ·5 c.c. of the culture medium to be tested was withdrawn with a sterile pipette and placed in a watch-glass, and to this a drop or two of the indicator solution was added, taking care that the culture liquid was distinctly in excess. The colour of the liquid in the watch-glass, placed on white paper could then be easily matched with the colours of Clark's chart, and differences of *p*H value to within ·1 could be estimated. Whenever possible two determinations were made with different indicators.

By using watch-glasses instead of test-tubes, difficulties in matching, due to turbidity, colour of the medium, reflections from the surface of the tubes, and dichroism of the indicator were largely avoided.

Series of standard tints in test-tubes made up according to Gillespie's (10) recommendations were used to check results especially when growth limits were being determined.

The points between $p\mathrm{H} = 4{\cdot}0$–$4{\cdot}8$, which include the acid limits of growth for many species, are especially difficult to estimate owing to the dichroism of bromphenol blue; in these cases the culture tests were also matched with the colour given by the same quantities of citrate buffer solutions placed in watch-glasses.

The escape of ammonia or volatile acids is naturally more rapid from watch-glasses than from test-tubes and the readings should therefore be taken at once.

In cases where the cultures were tested from day to day the inoculations were made in duplicate or sometimes in triplicate, in order to guard against errors due to contamination when introducing the pipettes.

II a. *Acid Limit of Growth.*

The degree of acidity at which growth ceases was determined by inoculating tubes of broth acidified with HCl to *p*H values 4·0, 4·4, 4·6, and 5·0, with the species to be tested, and incubating them for at least a fortnight. At *p*H = 4·0 no growth was obtained in any case.

The following list gives the highest degree of acidity at which growth was obtained:

	Parasitic species	Non-parasitic species
*p*H = 4·4	B. solanisaprus	B. coli (5·0 BDH)*
	B. atrosepticus	B. fl. liquefaciens
	B. lathyri	B. fl. non-liquefaciens
	B. campestre	B. pyocyaneus (6·0 BDH)
*p*H = 4·6	B. Barkeri	B. prodigiosus
	B. caratovorus	B. dendroides
	B. Tolaasi	B. lactis aerogenes
	B. solaniolens	B. faecalis alcaligenes (6·9 BDH)
	B. viridilividum	
	Ps. protea-maculans	
*p*H = 4·8	B. marginale	B. vulgare (6·5 BDH)
*p*H = 5·0	Apl. michiganense	B. violaceus
	Ps. phaseoli	B. subtilis
	Ps. Hyacinthi	B. mycoides
		B. megatherium
		B. mesentericus

* BDH indicates the value given in the list published by the British Drug Houses, Ltd.

It is of interest to note that no growth was obtained in any case in broth of acidity greater than *p*H 4·4, the value given by Pearsall and Priestley as the iso-electric point of many of the principal proteins of plant tissues (16).

As in the previous series of experiments a greater tolerance of acid is shown by most of the plant parasites and the types allied to *B. fluorescens* than by *B. vulgare* and the sporing species; the parasitic forms *Ps. hyacinthi* and *Ps. phaseoli*, however, seem particularly sensitive to acids, a fact noted by Dr Erwin Smith (20).

Advantage may be taken of the fact that plant parasites are more resistant to an acid culture medium than the common sporing organisms, to free cultures of the former from such contaminations. If material

from a diseased plant be inoculated into broth at *p*H 4·6–5·0 any growth during the first or second day will be practically free from such sporing organisms, as the latter only give a visible turbidity in about five days at *p*H = 5·0.

This treatment before plating is useful in the case of the "soft rot" and *Pseudomonas* groups, but is naturally of no avail with slow growing forms like *Aplanobacter* or *B. viridilividum*.

II b. *Alkaline Limits of Growth.*

The degree of alkalinity at which growth in peptone broth ceases was also determined; it was found to be approximately the same, *i.e.* *p*H 9·3–9·5 for all the species tested, both parasitic and non-parasitic, with the following exceptions:

B. faecalis alcaligenes	*p*H = 9·6 (9·7 BDH)
B. vulgare	= 9·2 (8·8 BDH)
Ps. hyacinthi	= 9·2
Aplanobacter michiganense	= 9·2
B. mycoides	= 8·9
B. viridilividum	= 8·9
B. pyocyaneus	= 8·8 (9·0 BDH)
Ps. phaseoli	= 8·7

Difficulty was experienced in getting the medium free from the turbidity due to the addition of alkali, but by mixing *N*/10 NaOH with broth in the proportions 1 : 3; 2 : 2; and 3 : 1 and then autoclaving, three series of tubes containing broth at *p*H = 8·2, 9·0, and 9·7 were obtained in which the turbidity was precipitated out and growth could be observed in the clear medium above. The hydrogen-ion concentration of these increased slowly, probably owing to absorption of CO_2 from the air; when the first trace of growth appeared, a small quantity of the broth was removed with a sterile pipette and its *p*H value tested colorimetrically. Every test was repeated and confirmed again in the course of later work.

In some cases free growth in the liquid medium was preceded by a slow growth on the surface of the glass, this was especially noticeable with *B. mycoides* and *Aplanobacter michiganense*. It was at first mistaken for a deposit from the broth. Sodium hydroxide appears to render the cell walls of the bacteria mucilaginous, but instead of agglutinating with one another they settle on the glass walls of the tubes. Attempts were made to get agglutination with alkaline solutions, but only a film of bacteria adhering to the glass was obtained in most cases, apart from chemical precipitates which were often very misleading. In spite of this

action of caustic soda on the cell walls, the bacteria are not quickly killed; emulsions of eight representative species were still living after three hours' immersion in decinormal sodium hydroxide.

III. CHANGE OF HYDROGEN-ION CONCENTRATION DUE TO BACTERIAL GROWTH.

It had been noted in previous work(4) that bacteria which were agglutinable in Michaelis' acetate solutions slowly developed an alkaline reaction during growth in peptone water, while certain species which were inagglutinable within the range of these solutions (pH 3·50–5·00)

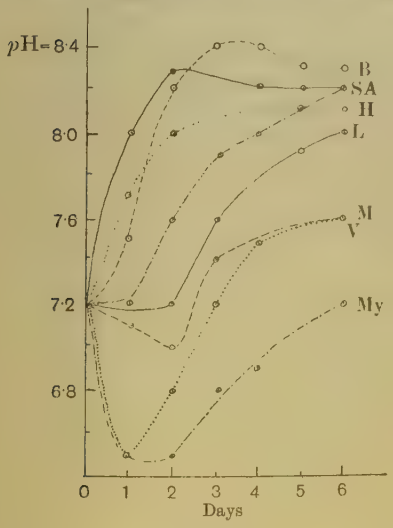

Fig. 1 a.

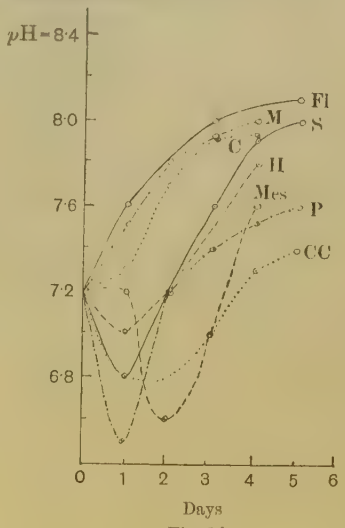

Fig. 1 b.

Fig. 1 a. Changes in pH value of cultures in peptone water during the first six days of growth. *B* = *B. Barkeri* (1·2); *S* = *B. solaniolens* (1·5); *A* = *B. atrosepticus* (1·2); *Fl.* = *B. fluorescens liquefaciens* (2·0); *L* = *B. lathyri* (3·0); *M* = *B. megatherium* (4·8); *V.* = *B. vulgare* (3·7); *My* = *B. mycoides* (5·0).

Fig. 1 b. Changes in pH value of cultures in peptonized Jardox broth during 4–5 days' growth. *Fl* = *B. fluorescens non-liquefaciens* (2·0); *M* = *B. marginale* (2·0); *C* = *B. caratovorus* (2·0); *S* = *B. subtilis* (3·7); *Mes* = *B. mesentericus* (5·4); *CC* = *B. coli communior* (3·7); *H* = *Ps. hyacinthi* (3·7); *P* = *B. prodigiosus* (1·5).

gave no alkaline reaction when tested with α-naphthol phthalein even at the end of three weeks. Twenty species were therefore inoculated into tubes of peptone water, the original pH value being 6·9. Each day small quantities were tested with the reagent.

Eight plant parasites and *B. fl. non-liquefaciens* gave the blue colour

indicating a fall of hydrogen-ion concentration below pH = 7·3 by the second day, *B. lathyri* gave it on the third, *B. coli* on the fifth, while three "ammonifying" organisms *B. mycoides*, *B. subtilis* and *B. vulgare* only gave coloration after the seventh day.

Further experiments confirmed this result that the bacterial species with high agglutination maxima rapidly produced alkali in peptone water, while the "ammonifying" organisms with lower agglutination points produced acid during the first day or two of growth and only later gave rise to an alkaline reaction in the medium.

The curves in fig. 1 represent these changes in pH value, due to the growth of several selected species of bacteria, in 5 c.c. of Dunham's peptone water, and fig. 2 gives similar curves for bacteria growing in peptonized Jardox broth. In the latter medium better growth was obtained, particularly in the case of the sporing organisms, but the changes in pH value were less marked, and the final pH values for the plant parasites were lower. These final pH values are always considerably lower than the alkaline limits of growth, probably because other toxic substances accumulate in the medium.

The agglutination optima of the various species are given in brackets in figs. 1 and 2, so that the correspondence between these and the rapidity of alkali formation can be readily recognized. In this series *B. prodigiosus* is exceptional in its behaviour. It resembles the parasites in its high maximum agglutination point, but forms acid, like the sporing forms, during the first two days of growth. Later experiments showed that it reacts to acid solutions by the production of alkali, but in neutral and alkaline media such as here used it produces acid.

Acid and Alkali Production in Nutrient Media of Varying Hydrogen-ion Concentration.

In order to determine whether the initial acidity of the medium had any influence on the formation of alkali during growth, tubes of peptonized broth, brought to various pH values with HCl and NaOH, were inoculated with a loopful of a 24 hour broth culture of each species; these were incubated at 21° C. for two days and the change of pH then determined.

The reaction of the *Pseudomonas* and *fluorescens* group to acidity of the nutrient medium is very marked, as is shown by the curves in fig. 2, where the abscissae represent the initial pH values of the medium, and the ordinates the change of pH in the cultures at the end of two days' growth: positive ordinates represent alkali formation, negative ones the development of an acid reaction. It will be seen that the cultures

giving greatest alkali formation are those of high initial acidity, not those of maximum growth, as evidenced by the earliest appearance of turbidity, and greatest turbidity at the end of 48 hours.

Rapid alkali formation in acid media is also a characteristic of the

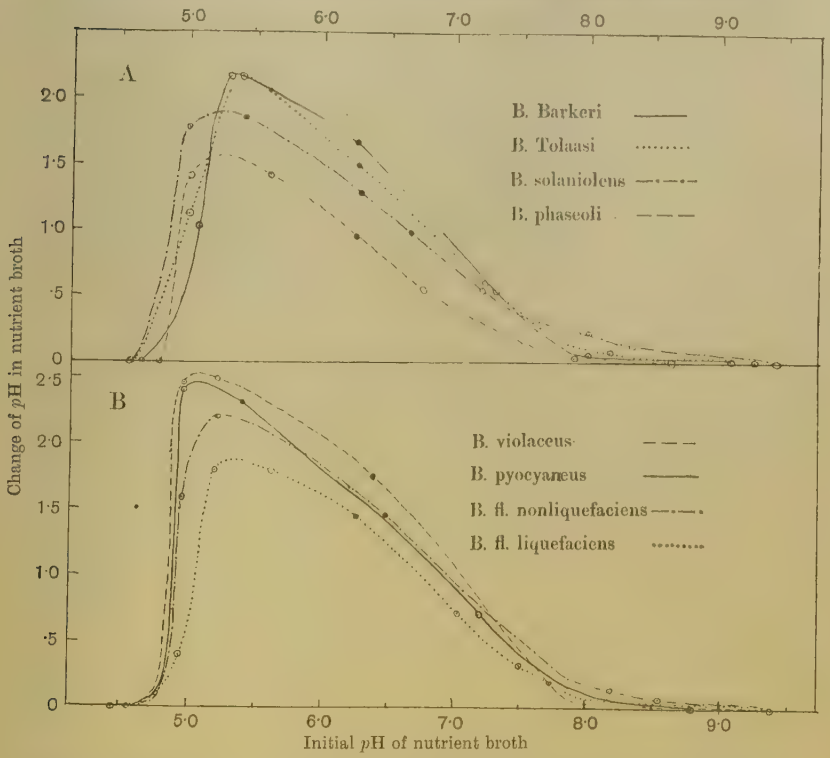

Fig. 2. Showing alkali production by various members of the *Pseudomonas* and *B. fluorescens* group in peptonized broth of varying hydrogen-ion concentration after 48 hours' growth. A. Plant parasites. B. Non-parasitic species. • Cultures showing maximum growth.

parasitic forms allied to *B. caratovorus*, but in this group there seems to be a slight tendency to form acid in alkaline media.

Most of the sporing species and also *B. vulgare*, on the other hand, form acid at all hydrogen-ion concentrations during the first two days of growth; the curves in fig. 3 illustrate the contrast between the behaviour of these organisms and that of the plant parasites. *B. dendroides*

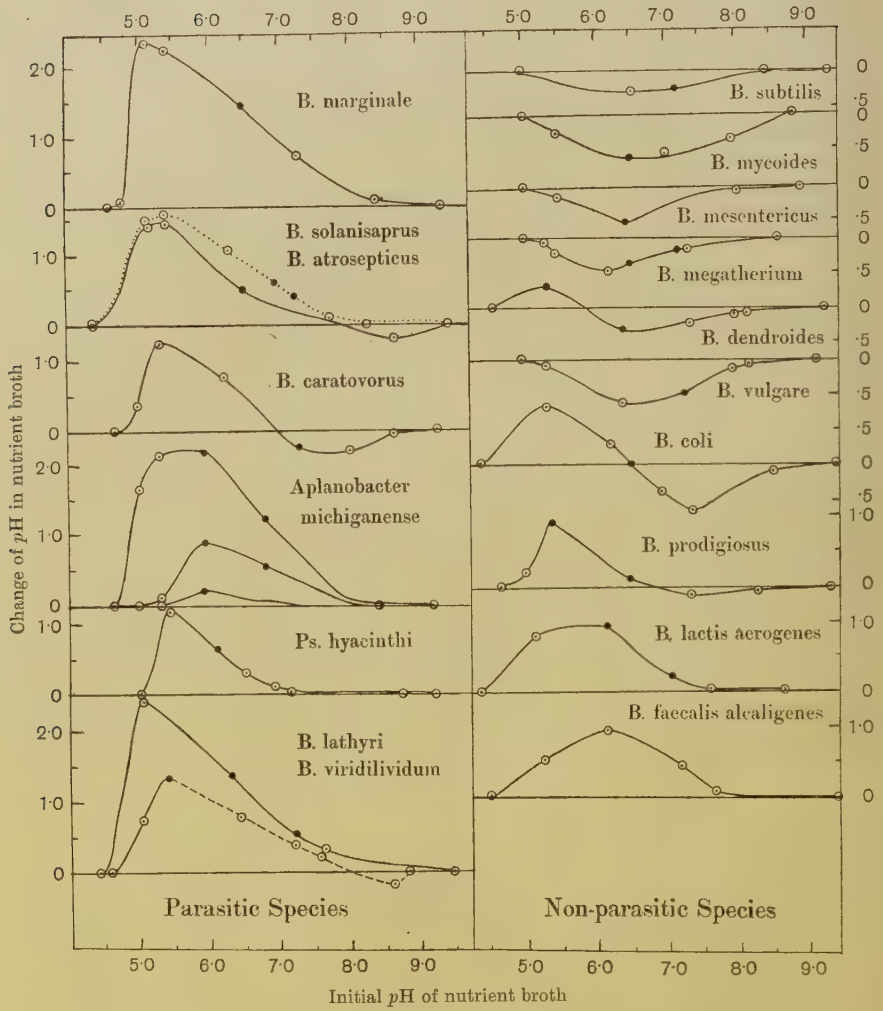

Fig. 3. Showing alkali or acid production by various species of bacteria after 48 hours' growth in peptonized broth of varying hydrogen-ion concentration. Positive ordinates = alkali production. Negative ordinates = acid production. • Cultures showing maximum growth.

appears to be an exception among the sporing organisms, like *B. coli* and *B. prodigiosus* it forms alkali in acid media and acid when the media is initially alkaline.

The non-parasitic forms *B. lactis aerogenes*, and *B. faecalis alcaligenes* were found to form alkali just as freely as many plant parasites.

SUMMARY AND DISCUSSION.

It is interesting to see in the foregoing series of experiments that most of the bacterial plant parasites, especially those of the *Pseudomonas* type, and the non-parasitic species of the *fluorescens* type seem to possess three associated characteristics, namely high acid agglutination points and limits of growth, and a capacity to produce alkali rapidly in the presence of nitrogenous food materials. This latter capacity is shown in a less marked degree by other non-sporing saprophytic organisms such as *B. lactis aerogenes*.

Many sporing species, on the other hand, appear to possess a different physiological constitution, since they produce acid in the earlier stages of growth in sugar-free peptonized broth, and are characterized by comparatively low agglutination points and growth limits. Tests by Marchal and other observers (14) at a later period of their development have caused these sporing organisms to be regarded as the chief ammonia producers in the soil.

The experiments also show that the hydrogen-ion only begins to act injuriously on the bacteria at concentrations about *p*H 5·0–4·4. Such hydrogen-ion concentrations are seldom met with in plant tissues except in the case of acid fruits. The acidity of the cell sap has been determined by several investigators by the hydrogen electrode method; Clevenger (8) found that it varied from *p*H 4·33 for Buckwheat seedlings to *p*H 6·40 for Soy bean leaves. The values obtained by Hoagland (11) for barley tops, by Phillips (17) for Indian Corn and *Vicia faba*, and by Wagner (21) by means of an indicator method for *Sinapis alba*, *Brassica oleofera*, *Solanum tuberosum* and *Sempervivum Hausmanni* all lie between *p*H 4·9 and *p*H 6·2. The cell sap used in these experiments was generally obtained by pressure of the tissues after grinding with sand; treatment of sections of fresh tissues with methyl red indicates that the acidity of the protoplasm itself is somewhat higher than that of the cell sap, whilst Atkins (1) found that the liquid centrifuged from the tracheae of *Acer pseudoplatanus* was neutral to litmus. Priestley (18) too remarks with respect to the sap collected from a bleeding vine stem, that, "tested with the usual series of indicators, the *p*H values of the sap in the vines was practically that of true neutrality."

The higher acidities of these plant extracts would be a serious check to growth and multiplication in the case of the sporing species only; they are quite too low to cause the death or even the agglutination of most of the bacteria here tested.

The low hydrogen-ion concentration in the vessels of the wood may account for the fact that the bacteria causing wilt diseases are at first confined to the vascular bundles, where they can multiply freely, they only attack the more acid parenchymatous tissues later when the latter have become disorganized by the blocking of the water channels.

It has been shown, however, by certain investigators that reduction in the acidity of the cell sap does, in some way, facilitate the attack of bacteria on plant tissues. Laurent(12) found that *B. coli communis* and other non-parasitic bacteria would rot slices of raw potato which had been immersed in a 1 per cent. solution of Na_2CO_3 or K_2CO_3 for one hour, but as he found that there was no relation between the total acidity of the juice of different varieties of potato and their resistance to the attacks of *B. coli* and *B. fluorescens putidum*, he concluded that this resistance was due to the existence in the cell sap of a soluble substance whose power was annihilated by alkaline substances.

Lepoutre(13) confirmed Laurent's work, and also claimed to have shown that turnips and carrots grown on plots treated with lime or salt or nitrogenous manures were less resistant to bacterial invasion, and were even attacked by the species *B. fluorescens liquefaciens*, *B. mycoides* and *B. mesentericus*, usually regarded as non-parasitic. On the other hand he considered that treatment of the soil with phosphoric acid rendered the plants less susceptible to infection.

Therefore, although it is quite obvious that the power to produce alkali rapidly from nitrogenous food materials does not by itself enable bacteria to live parasitically in plant tissues, since both parasitic and non-parasitic species may possess it in the same degree, yet it may be an important factor in enabling bacteria invading an open wound to produce an environment favourable to their own growth and development before cork formation limits their activities. In the case of the sporing species and *B. vulgare* the tendency to form acid from nitrogenous food materials as well as from carbohydrates, coupled with their agglutinability in comparatively low hydrogen-ion concentrations, would seem to render them incapable of attacking living plant tissues.

The writer wishes to express her thanks to Dr S. G. Paine for the interest and criticism so kindly given in the course of the work.

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THE EFFECT OF IODINE ON SOILS AND PLANTS

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(With 8 Text-figures.)

The occurrence of small quantities of chemical elements in plants, other than those usually regarded as nutritive in function, has been attracting an increasing amount of attention of late years, and theories have been advanced as to the functions of these elements in the economy of the plant. Leading on from this, investigations have been made as to the effect of these same elements when added to the substratum or nutrient medium upon which the plants are grown, especially from the point of view of the improvement of agricultural crops. Among these elements iodine has its place, and during recent years has been investigated from both the physiological and agricultural standpoints.

Several workers claim to have obtained improved growth of crops by the use of dressings of iodine. In view of the fact that small quantities of the element occur in such artificial manures as nitrate of soda and also in kelp an attempt has been made at Rothamsted to determine whether iodine can profitably be used in agricultural practice as a partial sterilising agent or as an accessory fertiliser. Both lines of investigation have been followed up simultaneously, a grant in aid being given by the Chilean Iodine Committee, which enabled the work to be carried out more thoroughly and over a longer period than would otherwise have been possible.

A. Historical.

(*a*) *Distribution.* Chatin(4) was one of the earliest workers on the distribution of iodine, and in the vegetable kingdom he detected its presence in the fossil remains of plants, in certain aquatic and terrestrial plants and in such fermented liquors as wine, cider and perry.

Stanford(18) analysed a number of marine plants and his figures indicate that deep-sea algae usually have a greater proportion of iodine than those that grow in shallow water. Amongst others he gives the following:

Deep sea	Percentage of Iodine	Shallow water	Percentage of Iodine
Laminaria digitata (A)	0·4535	Fucus serratus	0·0856
„ „ (B)	0·2946	„ nodosus	0·0572
„ saccharina	0·2794	„ vesiculosus	0·0297

Scurti(17) investigated the iodine content of marine algae from the physiological point of view, using *Sargassum linifolium* and *Cystoseira discors* as subjects, and concluded that iodine holds in the algae the place held by chlorine in the phanerogams, its function being that of an excitant of the reproductive phase. The iodine content was found to increase regularly from the beginning of the reproductive period to the beginning of maturation of the organs of fructification, and then to decrease with completion of maturation.

Gautier(8) carried the matter of iodine distribution further, his experiments indicating that iodine is a constant constituent of green algae, both marine and those of fresh water, though less is present in the latter. Certain sulphur bacteria contain iodine, but the element is an inconstant constituent of fungi and colourless algae. Gautier concluded that in green algae the iodine either enters into the constitution of the chlorophyll itself or into that of the protoplasm concerned with assimilation, occurring in the form of a nucleinic combination rich in both phosphorus and iodine. Hence it would appear to be essential for green algae, but merely supernumerary for such plants as fungi or tobacco in which it may or may not be present.

Cameron(3) found iodine in all green, brown and red algae examined, the quantity varying from 0·002–0·2 per cent., most occurring in *Laminaria*. Analyses of different parts of *Nereocystis lutkeana* showed marked differences, but in no definite direction, indicating no specific distribution of iodine in the plant. He suggests that iodine is an almost invariable constituent of all organisms, the amount depending on the diet and the medium of the organism. Winterstein(27) analysed thirty-five phanerogams and a few fungi, but only detected iodine in small amounts in beets, celery roots, lettuce, carrot and potatoes, about 0·002 per cent. occuring in the latter.

(*b*) *Effect on plant life.* Iodine has rarely been considered to be an essential element for plant nutrition, but Mazé(13, 14) claims that minute quantities of iodine, together with boron, aluminium and fluorine, are indispensable to the growth of maize in the same sense as nitrogen, phosphorus, potassium, etc. Experiments at Rothamsted (unpublished) do not altogether bear this out, as excellent plants have been obtained in water culture in the absence of iodine, but further tests are needed.

The more usual aspect from which iodine is considered is that of its toxic or stimulating action. Voelcker(25) found that sodium iodide exercised a very harmful effect upon the germination and growth of such crops as barley, mustard, wheat, clover and peas when applied at the rate of 5 cwt. per acre, the results with lighter dressings varying somewhat with the season and crop, though they were usually unfavourable. Soaking the seed in 1 per cent. solution of sodium iodide for twenty minutes before sowing occasionally seemed slightly beneficial. Heckel(11) found that iodine hastened the germination of *Raphanus raphanistrum*, while Moore(15) obtained stimulation of the same plant in both water and soil cultures, the optimum concentration appearing to be about $1\frac{1}{2}$ lbs. per acre. Japanese investigators, Aso and Suzuki(1), Uchiyama(23, 24) claim that small doses of iodine applied as potassium iodide stimulate the growth and production of various agricultural crops as rice, oats, barley, radishes, peas, sesamum and spinach, the optimum dressing varying from 25–500 grm. per hectare, and they suggest that the manurial value of seaweed may be due in some part to the iodine contained.

The efficiency of iodine as a fungicide appears to be doubtful, as Lodeman(12) sprayed various fruits with iodide of potassium solution, and found that, especially with quince, the injury caused to the foliage obscured its possible fungicidal action. In another direction Cooper and Walling(5) had some measure of success in destroying the larvae of blowfly by means of iodine vapour, 78 per cent. mortality being obtained when air saturated with iodine vapour was drawn over the larvae for $3\frac{1}{2}$ hours.

B. Iodine as an Agent for Partial Sterilisation.

Several soils of varied history were obtained from farm and greenhouse, some of the latter being definitely classed as "sick" and therefore more likely to show response to the action of a partial sterilising agent. After treatment with various forms and strengths of iodine or other substances to act as controls, bacterial counts on Thornton's count medium(22) were made at 5 or 10 days intervals over periods extending from 10 days to 16 weeks. In the earlier experiments the soils were placed in the usual way in bottles plugged with cotton wool and kept at room temperature in a laboratory cupboard. Later on, in order to approximate more closely to the conditions to which partially sterilised soils are subjected in greenhouse cultures, the treated soil was placed in new unglazed earthenware pots, coated with pure white paraffin wax inside and out to prevent undue evaporation or any interaction between the

porous pot and the soil. Each pot was weighed when filled, and as far as possible kept at this weight throughout the experiment by the addition of distilled water, in order to maintain a fairly constant moisture content. The actual water content in each case depended upon the initial moisture content of the soil used, as a certain amount of extra water had to be added to carry the solutions of iodine and other substances. The pots were kept in the greenhouse and were therefore subjected to the fluctuations of temperature normal to such conditions. With every soil one or two strengths of I in NaI solution were tested against untreated controls and in certain instances sodium iodide, iodoform dissolved in alcohol or ether, and cresylic acid were investigated in addition. An account of each soil and the results obtained therefrom is given to provide the data upon which the final conclusions are based. As iodine is so sparingly soluble in water and it was desired to have a certain amount of uncombined iodine in the dressings used, 12 grm. iodine with 18 grm. sodium iodide were made up to 2·724 litres with distilled water, giving a stock solution containing 1 grm. iodine per 100 c.c., partly in the elemental and partly in a combined state. This solution in appropriate dilutions was used throughout except where otherwise indicated.

1. *Unmanured soil from Little Hoos Field, Rothamsted*, as used in the pot culture experiments (see pp. 99–101).

Moisture content after treatment = 18 per cent.

A preliminary trial was made with five strengths of iodine, as I in NaI, from ·00095–·019 grm. I per kg. soil, to correspond fairly closely with the amounts received by the pot cultures running at the same time. Plates were poured 5 to 15 days after treatment, and counted 10 days later. The counts suggested that at first a considerable depression was caused by the iodine treatment, being more marked with the smaller doses, but that after a longer interval the bacterial numbers, with the heavier dressings especially, rose considerably above the untreated controls (fig. 1). This was repeated with the heaviest and lightest dressings (·019 and ·00095 grm. I), pourings being made one day after treatment and then at five successive five-day intervals. The initial depression with iodine five days after treatment was again obtained, but the later rise above the control was not obtained, the difference in the counts being within experimental error (fig. 2).

2. *Old cucumber soil* from Mr W. B. Randall, Harpenden.

This soil had been turned out of the greenhouse for some time and

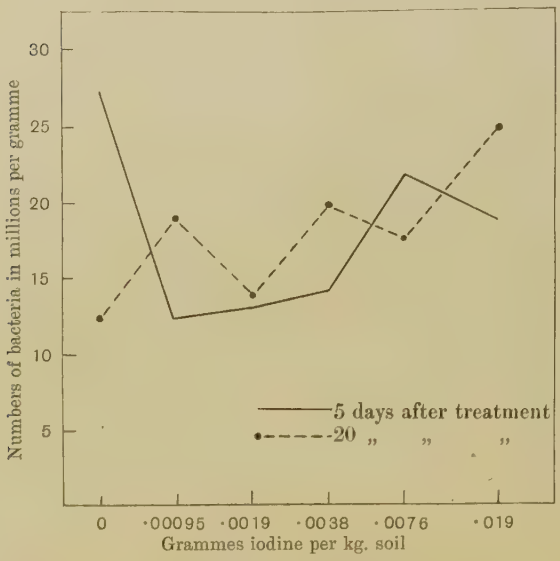

Fig. 1. Bacterial numbers in Little Hoos soil, Rothamsted (1), after treatment with various strengths of iodine.

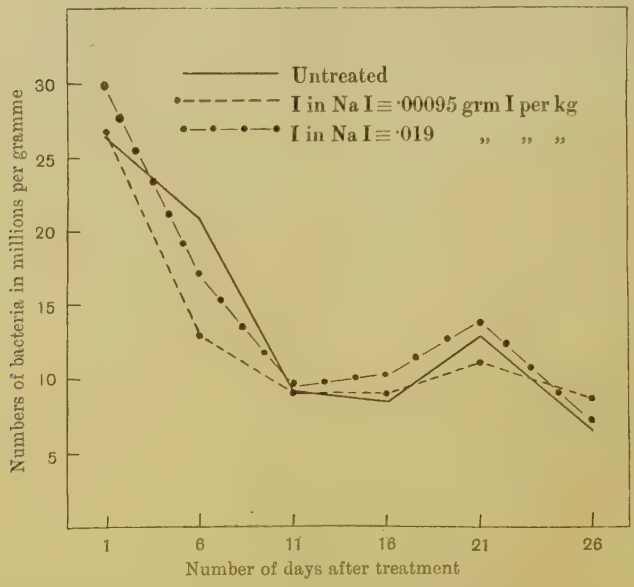

Fig. 2. Bacterial numbers in Little Hoos soil (1), after treatment with iodine.

exposed to the weather, and was consequently very moist owing to the large quantity of organic matter present, though it was friable, sifted easily and did not cake when worked.

Moisture content after treatment = 43·95 per cent.

Tested: I in NaI = ·019 and ·0038 grm. I per kg. The waxed pot method was used in this test and henceforward.

The heavy dressing of iodine had an immediate effect in considerably raising the bacterial numbers, by 25 millions per grm. over the control which gave 87·5 million per grm. This increase was maintained for ten days and then disappeared, the lower dressing having no significant effect throughout (fig. 3).

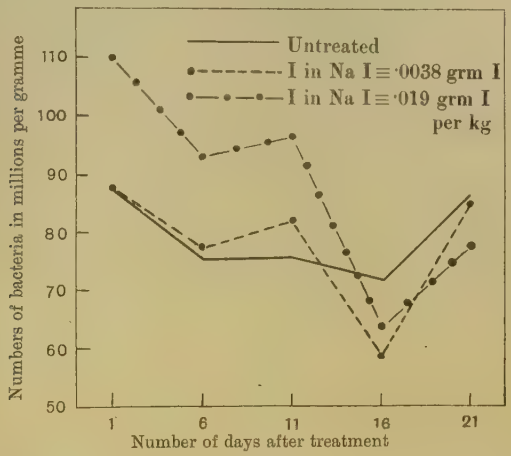

Fig. 3. Bacterial numbers in old cucumber soil, Harpenden (2), after treatment with iodine.

3. *Tomato sick soil*, from Mr Matthews, Shrewsbury.

This soil has had tomatoes grown in it for 20 years and has not been treated at all in the way of partial sterilisation, either by steam or chemicals. The plants are now doing very badly and the season before receipt (May 1923) the grower had had to replace fifty per cent. of them.

Moisture content after treatment = 21·4 per cent.

Tested: I in NaI = ·019 and ·0076 grm. I per kg. soil.

Iodoform = ·0076 grm. I per kg. soil.

Cresylic acid = ·25 per cent.

As an aqueous solution of iodoform could not be made, a weighed amount of iodoform was dissolved in as little alcohol as possible and the solution very thoroughly mixed with fine dry sand in such quantity that 10 grm. of the treated sand would contain the requisite amount of iodoform for one pot. The sand was spread out on a clean sheet of glass to allow the alcohol to evaporate, and then 10 grm. was intimately mixed with the weighed amount of soil for each pot. To keep the treatment uniform 10 grm. of similar sand, but untreated, was added to each of the other pots in the series. Cresylic acid was used in this experiment to provide a contrast with an agent with known powers of partial sterilisation, the amount applied corresponding to one of the heavier dressings used in commercial practice. Counts were made at five-day intervals for three weeks and an additional set of pots was carried over for 16 weeks before pouring, to ascertain if any effect were noticeable after the lapse of some considerable time from treatment. With this soil the I in NaI proved ineffective throughout with both dressings, the curves of bacterial numbers running close and fairly parallel to that of the untreated control. Cresylic acid showed the expected drop directly after treatment, followed by a steady rise, until after three weeks the numbers were approaching those of the untreated and iodine soils. The dressing of cresylic acid would appear to have been rather too heavy, for the anticipated large rise in bacterial numbers, after the initial fall, had not begun to show itself three weeks after treatment. As no counts were made between July and October, it remains uncertain whether the rise ever manifested itself. An interesting point occurred in the October counts, as every plate from cresylic acid treated soil was filled with a heavy growth of mould, which did not appear in any of the controls or iodine or iodoform plates. This suggests some encouragement given to moulds by cresylic acid, and might be worth following up in view of the variable results sometimes obtained when this agent is used for partial sterilisation by market gardeners.

The soils dressed with iodoform manifested a striking increase in bacterial numbers five days after treatment, succeeded by a similar rapid fall within ten days more to the level of the controls (fig. 4). This rise to 325 millions per grm., compared with the control 50 millions, can hardly be fortuitous, though no adequate explanation is as yet forthcoming. The iodoform was carried in alcohol as a solvent, which was evaporated before application to the soil. Under these circumstances, if the iodoform were the active agent, the effect should be reproduced when other solvents, such as ether, were used, but further tests (see 4

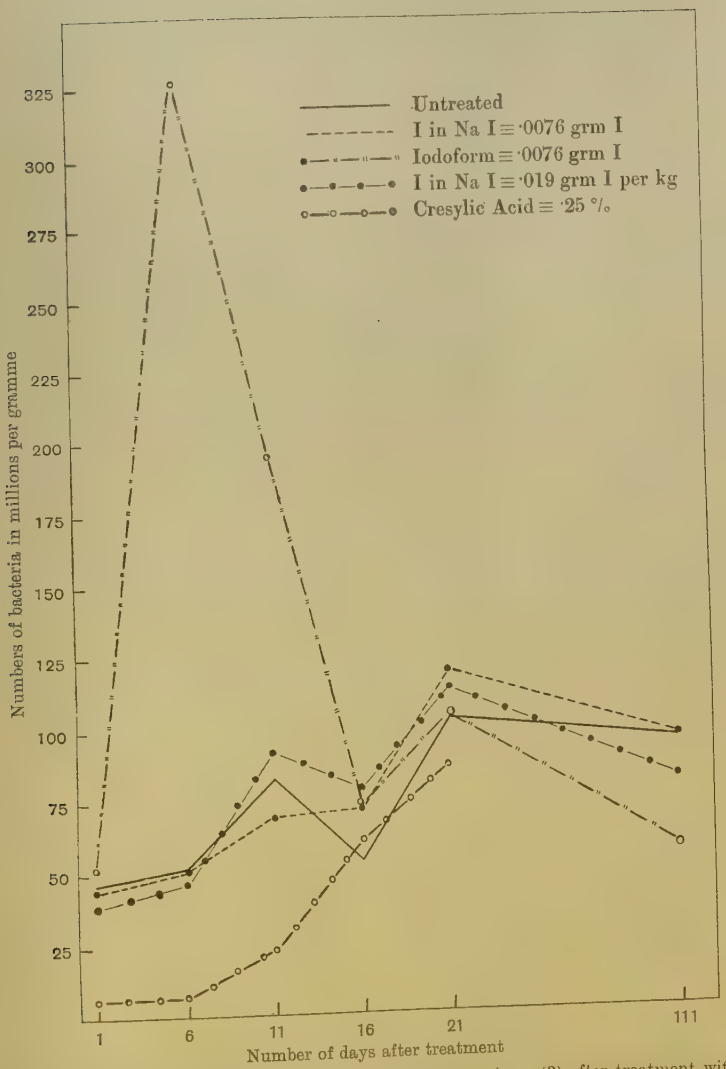

Fig. 4. Bacterial numbers in tomato-sick soil from Shrewsbury (3) after treatment with iodine or other reagents.

and 5) did not seem to bear this out to any extent. Suspicion was directed to the purity of the alcohol, which was the ordinary stock alcohol stored in metal drums. The quantity used amounted to about 1 c.c. for each 10 grm. sand, *i.e.* for each pot treated. It is inconceivable that any residue that may possibly have been left by this small amount of alcohol should contain sufficient bacterial food, presumably nitrogenous in nature, to provide nutriment for such a large number of organisms. So one is faced with the remaining proposition that the alcohol left a residue which in some unexplained way greatly stimulated the division of bacteria for a short time after application, the effect wearing off rapidly after the first few days. This point could not be followed up immediately as no more of the soil was available, but it is hoped that further supplies may shortly be obtained enabling more extended tests to be carried out. At the end of three months less bacteria were present in the iodoform soils than in the others, but no weight can be placed on this isolated result.

As the effect of partial sterilisation is shown not only by rise in bacterial numbers, but also by increase in the amount of nitrate and ammonia present in the soil, the quantity of these was estimated at each pouring for every treatment in the experiment (Table I). The normal course of events was illustrated with cresylic acid, in which the ammonia rose from 2·24 p.p.m. to 13·4 p.p.m. in 15 days, and then fell off, being at the original level again when examined after 16 weeks. The untreated controls showed no ammonia on any occasion, and very little was present with either strength of I in NaI except on two occasions with the heavier

Table I. *Nitrogen in parts per million in soils on days bacterial plates were poured.*

	June					Sept.
	7th	12th	17th	22nd	27th	25th
N as NH_3						
Before treatment, June 6th, 0·56 p.p.m.						
Control	nil	nil	0·56	nil	nil	failed
·0076 grm. I ...	0·56	0·12	0·56	1·12	1·12	0·89
·019 „ ...	1·12	0·56	3·35	1·68	1·12	3·13
Iodoform ...	4·24	2·24	1·12	1·12	1·12	0·89
Cresylic acid ...	2·24	7·81	10·05	13·40	10·95	2·12
N as N_2O_5						
Before treatment, June 6th, 121·1 p.p.m.						
Control	122·3	121·1	122·1	120·6	77·20	15·15
·0076 grm. I ...	115·9	125·3	125·0	110·3	60·38	12·56
·019 „ ...	119·9	125·3	123·6	117·3	62·30	19·55
Iodoform ...	118·6	109·4	111·6	115·9	73·76	48·82
Cresylic acid ...	120·1	113·8	116·3	111·9	109·20	21·64

dressing when a slight increase occurred. In view of the bacterial rise with iodoform, however, it may be significant that 1 p.p.m. ammonia was present in the soil one day after treatment, though this amount fell within 10 days to the level of the I in NaI soils and remained there throughout.

The nitric and nitrous nitrogen of the untreated soils remained very constant for the first 15 days, fell rapidly during the next five days, and by the end of 16 weeks was down to only 15 p.p.m. instead of 122 p.p.m. at the beginning. With the various iodine treatments slight fluctuations, which are of doubtful significance, occurred during the first 15 days, followed by a similar fall to that with the control, though at the end of 16 weeks the iodoform soil still contained far more than any of the others. The rapid fall in nitrogen as N_2O_5 between June 22nd and 27th is difficult to understand, as no plants were growing in the soil, but duplicate tests were made to prove the accuracy of the analyses. With cresylic acid the beginning of the fall was delayed, but ultimately the amount approximated to that in most of the other soils.

The failure to obtain definite partial sterilisation effects with iodine, as evidenced by increase in bacterial numbers, would therefore seem to be borne out by the estimations of nitrogen in the soils, the only suggestive correlation being that of the initial rise in bacterial numbers and increase of ammonia in soil treated with iodoform.

4. *Tomato soil from Mr Matthews, Shrewsbury,* which had carried tomatoes for six years.

Moisture content after treatment = 19·55 per cent.

Tested:	I in NaI	= ·0076 grm. I per kg. soil.
	Sodium iodide	= ·0076 „ „
	Iodoform in ether	= ·0076 „ „
	Ether alone	1 cc. per pot, evaporated off

In view of the possible interaction of alcohol residues in the iodoform treatment the reagent was dissolved in ether, mixed with sand and evaporated off as before. A further check was applied by treating soil with ether alone, to find out whether any action occurred therefrom, any difference between the two series being presumably attributable to the iodoform.

No evidence of partial sterilisation could be deduced from the bacterial counts, though for some days the numbers with iodoform were considerably above those of the controls. Nevertheless the curves run so very parallel in direction, and the differences in number between

one treatment and another are so slight that they cannot be regarded as significant (fig. 5).

No repetition whatever was obtained of the great rise in bacterial numbers with iodoform at the beginning of the test, leaving it still an open question as to whether this previous rise was due to the alcohol used as a carrier. Throughout the experiment the iodoform soil was richer in bacteria than that receiving ether alone, especially towards the end, and on some dates the difference was sufficiently great to suggest a true increase arising from the use of iodoform. This soil is very poor

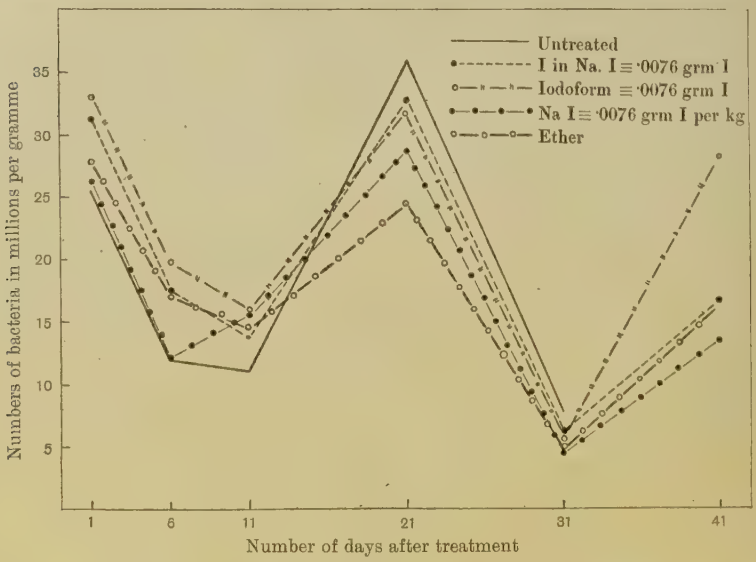

Fig. 5. Bacterial numbers in tomato soil from Shrewsbury (4) after treatment with iodine.

in bacteria, only 3·7 millions per grm. being present before treatment, as compared with 8·6 and 10·0 million per grm. in soils 3 and 5 respectively. Examination for protozoa revealed a great paucity in the number of species, both actually and in comparison with those in the other two soils.

5. *Tomato soil from Mr J. C. Randall, Waltham Cross*, which had carried tomatoes since 1919 and had not been partially sterilised. The house from which the soil was taken was a poor one as regards cropping, but this may have been due to defective heating rather than to "sickness" of the soil.

Moisture content after treatment = 26·763.

The tests were repeated as under (4), except that the equivalent amount of iodine was ·019 grm. per kg. soil. In this case the relative numbers of bacteria were less regular than in any of the previous tests, the curves of the counts being much less parallel (fig. 6). The irregularities were such, however, that no evidence was obtained of any constant or definite effect of any of the dressings employed, and again the iodoform carried in ether did not show the rise obtained with alcoholic iodoform.

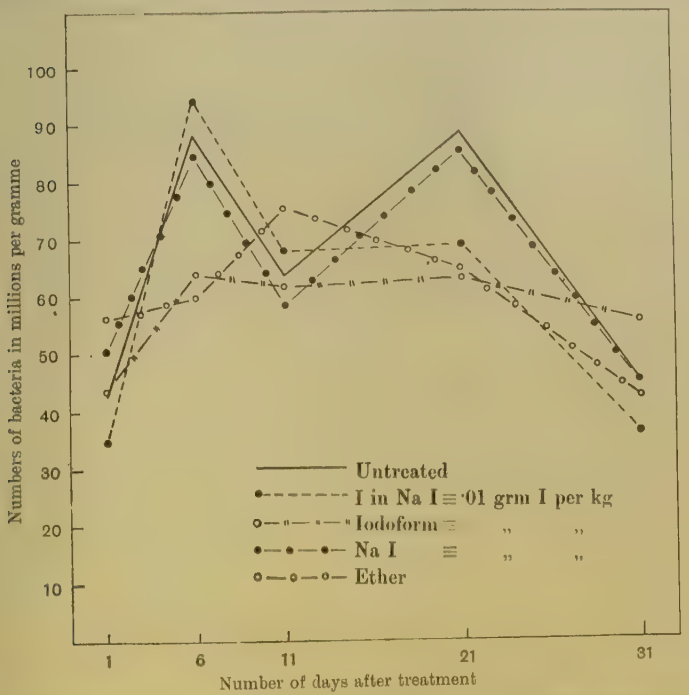

Fig. 6. Bacterial numbers in tomato soil from Waltham Cross (5) after treatment with iodine.

The results set forth above have been obtained from a consideration of various soils after treatment with iodine presented in different combinations and concentrations. In some cases the effect produced by the iodine, even if fairly constant, was too small to be regarded as of any significance, if, indeed, it was not within the limits of experimental error. In other cases, in which iodine occasionally produced consider-

able increase or decrease in bacterial numbers the variations were too irregular and inconstant to indicate any definite partial sterilisation brought about by the iodine, the bacterial numbers in the treated soils ranging above or below those of untreated soils at different times. The only very great increase lies under suspicion on account of the possible impurity of the alcohol carrier, but is sufficiently outstanding to justify further work if the necessary soil can be obtained.

C. Effect of Iodine on Germination and "Damping off" of Seedlings.

In order to gain some idea whether iodine dressings would improve the germination and early growth of tomatoes in reputed "tomato sick" soil, glazed pots holding 5 or 6 lbs. were filled with the soil from Shrewsbury and Waltham Cross used in tests (3) and (5) above, one-third being left untreated, and the others dressed with ·019 and ·0076 grm. I per kg. soil, applied in the usual solution of iodine in sodium iodide. In order to give any partial sterilisation time to take place sowing was delayed for three weeks, except with some of the Shrewsbury pots which were sown after 10 days. During the interval the pots were kept moist, and then each received seven seeds of Sutton's Early Market, duplicate or triplicate sowings being made for each treatment. In no case did any obvious difference appear either in the rapidity of germination or in the initial vigour of the seedlings in the treated and untreated pots, but after three to five weeks, according to the date of sowing, the plants in the iodine-treated soils were rather taller and had formed larger and better leaves. At this stage the seedlings were thinned out to 1 per pot, and for some time after the plants in the untreated soils remained behind the others in development in the Shrewsbury soil, whereas in the Waltham Cross soil they soon took the lead. As the experiment was only designed to test the effect on germination and small pots were used in consequence, it was soon necessary to feed the plants rather heavily, and any initial effect due to the iodine treatment was swamped in consequence. As a matter of interest a record was made of the amount of fruit produced per plant, but no practical results issued therefrom.

In yet another connection experiments were carried out by Dr Bewley, at Cheshunt, to determine whether treating the soil with iodine before sowing would reduce the percentage of loss from "damping off" of seedlings. The same stock solution was used as at Rothamsted, iodine in sodium iodide containing 1 grm. I per 100 c.c., and the normal solution used in the tests was 1·2 c.c. of the stock in 10 ozs. water. Tests were

made with quantities varying from 5 to $\frac{1}{5}$ normal, against controls receiving distilled water only, and with each concentration two boxes containing seven pounds of soil received 10 ozs. of the appropriate solution, afterwards being sown with 100 seeds apiece. The percentage of germination was not affected by any of the treatments and the variation in the percentage of diseased seedlings bore no relation to the amount of iodine used, no benefit being thus derived from the application (Table II). With five times normal solution germination was retarded and the shoots were dark green, but ultimately the percentage results resembled those with all other dressings.

Table II. *Effect of Iodine on "damping off."*

Treatment	% germination	% diseased
5 normal	98	11
2 „	97	15
1 „	97	17
$\frac{1}{2}$ „	98	13
$\frac{1}{5}$ „	99	10
Control (dist. water)	97	15

D. Effect of Iodine on Plant Growth.

The main experiments were carried out in pot cultures with mustard and barley, but further tests were made in water cultures with other plants. Mustard and barley are useful foils for one another in investigations of this kind, as mustard represents a type of crop that is cut green, before it has fully completed its reproductive phase, whereas barley is one of the group in which the ripe seed is the most important desideratum, and in which growth is allowed to continue until it practically ceases. It may well happen that some specific substance added to the soil may exercise a beneficial or a toxic action while vegetative growth is in full swing, but that the difference may become less marked as the plant nears the end of its life and ripens its seeds. On the other hand, the reverse may possibly occur, and the action of the specific substance only become manifest in the reproductive phase.

Experiments A. Soil treated Aug. 30th, 1922.

The initial tests were made in unmanured heavy loam in pots containing about 10 kilos (23 lbs.), to each of which was added a basal dressing of 4 grm. 35 per cent. super, 1 grm. K_2SO_4, 1 grm. $NaNO_3$, a further 1 grm. $NaNO_3$ being applied as a top dressing during growth. Iodine in sodium iodide solution was applied at the rate of 1·0, 0·2, 0·04, 0·008 grm. I per pot, equivalent to approximately ·1, ·02, ·004, ·0008 grm. I per kg. of soil. The required amounts of stock solution

were made up to 100 c.c. with water and applied evenly over the surface, another 100 c.c. of water being similarly applied when the seeds were sown a day later, mustard and barley being tested. Further watering was carried out through a porous pot sunk into the soil.

Mustard. Sown Aug. 31st, 1922. Cut Dec. 19th, 1922.

Iodine exercised a distinctly harmful effect upon germination. With the heaviest dressing a few seeds chitted, but the tiny rootlets soon died and no plumules emerged, while with one-fifth the dressing a very few plants survived and developed small plumules. Even ·04 grm. I per pot considerably reduced the number of seeds that germinated, and also the vigour of the young plants, but the weakest dose, ·008 grm. I, gave a stand equal to that of the untreated control pots. The plants were thinned to three per pot, and those with ·04 grm. I gradually recovered from their initial check and ultimately resembled the controls. The most striking feature, however, was the behaviour of the plants with ·2 grm. I. At first it was uncertain whether they would live or die, the seedlings being dark, unhealthy and very poor, but after about a month growth set in in earnest, though very irregularly. Rapid improvement took place, the leaves becoming larger than usual, though the colour was pale and the texture soft and succulent, until at harvest time some of the plants appeared as good as the controls, though shorter on the average. The green weights showed a gradual rise with increase in the dressing of iodine, very little significant difference appearing in the dry weights. The percentage of nitrogen in the dry matter and the total nitrogen removed by the plants tended to increase with the iodine. This increase in nitrogen, though not great, was consistent throughout, and if corroborated by further experiments might be a matter of importance, especially if correlated with the heavier green weight, as for crops that are cut green the latter would provide increased bulk associated with higher nutritive value due to the extra nitrogen.

Table III. *Mustard. Average of six pots.*

Iodine per pot grm.	Av. height of plants cm.	Green weight grm.	Dry weight grm.	% dry in green	% N in dry	Total N grm.
Control. No. I	68	97·21 ± 1·23	13·28 ± ·18	13·68 ± ·20	3·13	·402
0·008	72	99·31 ± 2·15	12·28 ± ·29	12·42 ± ·29	3·24	·398
0·04	65	103·98 ± 2·62	12·83 ± ·36	12·36 ± ·23	3·42	·440
0·2	58	111·56 ± 4·37	11·96 ± ·78	10·75 ± ·65	3·70	·443

Barley. Sown Sept. 5th, 1922. Cut Nov. 20th, 1922.

It soon became evident that barley is much more sensitive than

mustard to the toxic action of iodine. With the heaviest dressing no sign of germination occurred, and with one-fifth the dose a few seedlings appeared above the ground, but made no further growth and soon died off without developing. ·04 grm. I per pot hindered germination and growth, but whereas with mustard the plants with this strength made a rapid recovery from the initial injury and ultimately surpassed the controls, no signs of such recovery occurred with barley, the green weight at the time of cutting being reduced to 75 per cent. and the dry weight to 56 per cent. of that of the controls. The weakest dressing, ·008 grm. I per pot, had no effect on germination or growth, both green and dry weights tallying remarkably well with the controls. There was thus no evidence of any beneficial or stimulating action in this instance with barley. The crop had to be cut before ears were formed as it was grown late in the year and danger threatened from mildew.

Table IV. *Barley. Average of six pots.*

Iodine per pot grm.	Green wt. grm.	Dry wt. grm.	% dry in green	% N in dry	Total N grm.
Control. No. I	40·36	5·38	13·31	5·13	·276
0·008	40·78	5·28	12·96	5·21	·276
0·04	30·26	2·99	9·85	5·78	·173
0·2	—	—	—	—	—

The percentage and actual nitrogen present in the crop were unaffected by the smallest dose of iodine, and though the percentage of nitrogen was higher with a dressing of 0·04 grm. I per pot the total nitrogen present was considerably less than in the controls, affording no comparison in this respect to the mustard plants treated to correspond.

As the gradual recovery of retarded mustard plants in the parallel experiment indicated a reduction in the toxicity of iodine dressings as time went on, barley was sown again three weeks after the soils had been treated in the pots in which it had previously failed, *i.e.* with 1 grm. and 0·2 grm. I per pot respectively. All the seeds germinated within a week, but while those with 0·2 grm. I made good growth and did not seem at all adversely affected at any stage, those with 1·0 grm. I were small from the beginning and made very little growth, eventually dying off in about six weeks. This provides clear evidence of the reduction in toxicity with time, a reduction that was practically complete with the lighter dressing, but with the heavier dressing tried was not sufficiently great to permit normal growth, though distinct improvement was effected, as shown by the fact that the seeds germinated and made some growth in soils in which originally no signs of germination occurred.

Experiments B. Soil treated Feb. 27th, 1922.

In order to determine how rapidly and completely the toxic effect of heavy doses of iodine would pass off, and also to find out if the toxic action would then be replaced by a beneficial one, a series of sowings of barley and mustard were made in pots treated on the same day. The soil was manured as in Exp. A, except that 2·5 grm. sodium nitrate was supplied per pot for mustard, 2 grm. for barley, two series of pots being treated with light and heavy dressings of iodine in sodium iodide solution, a third series being left untreated. Three pots of each were sown the day after treatment and the rest at seven-day intervals over a period of five weeks.

About eleven weeks after the soil was treated with iodine additional sodium nitrate was applied as a top dressing dissolved in water, 1·0 grm. per pot to mustard, 0·5 grm. per pot to barley.

Mustard. Sown Feb. 28th, 1922, and at weekly intervals. Harvested June 18th.

When sown *one day after treatment* germination was affected as in the previous experiment, the plants with the light dressing recovering fairly soon, those with the heavy dose remaining small and irregular for several weeks, after which they began to grow very vigorously, ultimately surpassing the others in height and stoutness of stem. Flowering, however, was delayed by treatment by about a week with the heavy doses. The green weights showed the same rise with iodine as before, the dry weights being fairly level, with a possible increase with heavy iodine.

With a delay of *one week after treatment* before sowing germination was still affected with both doses of iodine, but recovery was more rapid, and within a fortnight the treated plants were as large as those sown a week earlier, indicating that the harmful action had been in some degree mitigated by the delay. The same retardation of flowering occurred with the heavy iodine dressing, but the plants at harvest time looked quite as good as the controls, though more succulent. The green and dry weights showed a considerable increase over the controls, and also the percentage of dry matter in green was rather higher. The light dressing of iodine, however, did not yield similar increases, the figures not being significantly different from those of the controls. As the period of delay before sowing was prolonged the check to germination caused by iodine decreased, until after four weeks it was hardly noticeable. With the improved germination less initial injury was manifest and the recovery therefrom was less marked, apparently not being followed

by a corresponding stimulation of growth as would have been the case had the toxic effect of iodine given way to a beneficial action. Statistical examination of the weights of the plants and consideration of the experimental errors involved show that there is no significant difference between

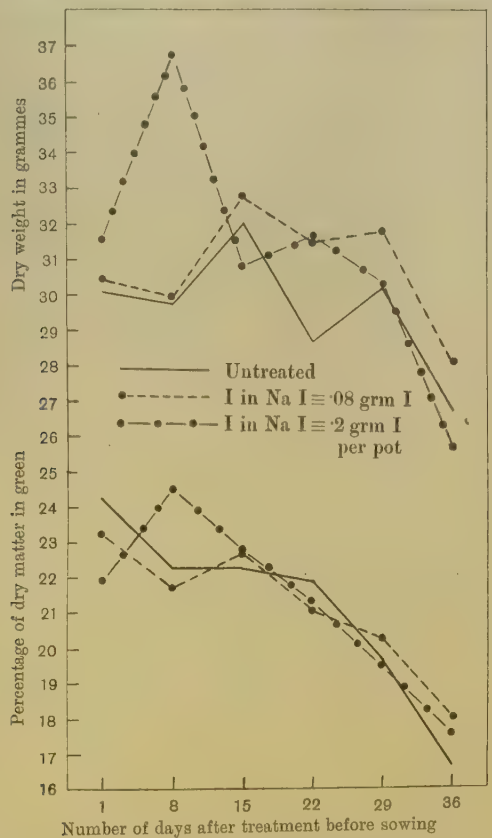
Dry weight in grammes
Percentage of dry matter in green
Untreated
I in Na I ≡ ·08 grm I
I in Na I ≡ ·2 grm I per pot
Number of days after treatment before sowing

Fig. 7. Dry weight and percentage of dry matter in green in mustard sown at varying periods, after treatment of the soil with iodine.

the control and iodine treated plants except in the case of the rise with the heavy dressing after one week's delay before sowing (shown by figures in black type in Table V). The general fall in the dry weight shown in the curve (fig. 7) is due to the decreasing age of the plants, the

Table V. *Mustard. Average of three pots.*

Treatment (iodine in grm. per pot) and time of delay before sowing	Green wt. grm.	Dry wt. grm.	% dry in green	% nitrogen	Actual nitrogen present av. per pot
1 *day*					
Untreated	124·26	30·08	24·23	1·645	·495
0·08	130·89	30·42	23·26	1·640	·499
0·20	144·08	31·54	21·94	1·875	·591
1 *week*					
Untreated	133·80	29·75	22·24	1·647	·490
0·08	137·7	29·97	21·71	1·807	·542
0·20	**150·3**	**36·72**	**24·47**	1·568	·576
2 *weeks*					
Untreated	142·98	31·99	22·43	1·650	·528
0·08	144·67	32·77	22·64	1·603	·525
0·20	135·53	30·80	22·72	1·827	·563
3 *weeks*					
Untreated	130·83	28·64	21·88	1·675	·480
0·08	149·62	31·43	21·04	1·644	·517
0·20	149·65	31·68	21·30	1·748	·554
4 *weeks*					
Untreated	153·72	30·15	19·65	2·002	·604
0·08	156·96	31·77	20·24	1·927	·612
0·20	155·77	30·32	19·50	1·945	·586
5 *weeks*					
Untreated	160·92	26·68	16·64	2·098	·560
0·08	156·48	28·07	17·99	2·127	·597
0·20	144·77	25·65	17·56	2·111	·535

corresponding rise in the green weights (Table V) being associated with the greater degree of desiccation that had occurred in the older and more mature plants, the combination of the two factors being reflected in the almost steady fall in the percentage of dry matter in green, only broken seriously by the marked rise with the heavy treatment sown after a week's delay. The percentage of nitrogen present in the dry matter of the plants varied somewhat at first with the treatment, but not in any definite direction, though it showed a slight tendency to be higher with the heavy dressing of iodine. After about three weeks' delay before sowing the percentage rose somewhat and was practically the same with every treatment. The actual amount of nitrogen absorbed by the plants was greater with the larger dose of iodine for the first four sowings, the increase tending to get less as the time of sowing was more delayed. After this the tendency appeared to be in the other direction, but the irregularity of the dry weights at the last sowing indicate that little significance can be attached to this point. The consistent increase of

nitrogen with heavy dressings of iodine at four successive sowings suggest that the iodine has some influence upon the absorption of nitrogen in the plant, which persists for a longer time than the influence upon the dry weight production.

The extra nitrogen supplied to the soil as nitrate of soda was 0·5765 grm., and with the earlier sowings it rarely happened that the nitrogen present in the plants amounted to as much as that except with heavy iodine dressings, showing that an ample supply of nitrogen was available, as the equivalent of the original store in the soil remained untouched. With the two latest sowings, however, nitrogen absorption was considerably greater, being usually above the amount presented as nitrate of soda.

If, therefore, iodine exercises any true beneficial action on the growth of mustard, it is to be looked for when a heavy dressing is applied and sowing is delayed for about a week, when a somewhat irregular and abnormal crop is to be expected, subject to the danger of loss if adverse conditions should prevail when the plants are very young and still suffering from the check due to the preliminary toxic action of iodine. The increase of nitrogen content continued after this period might be advantageous under certain circumstances, but is probably too slight to be of any real significance.

Barley. Sown Feb. 28th, 1923, and at weekly intervals. Harvested Aug. 8th, 1923.

When sown *one day after treatment* germination was delayed for a few days with the heavier dose of iodine, and when the plants did appear they remained very small and were of an unhealthy dark green colour. Little progress was made, and within three weeks all were dead. With the lighter dressing germination was not hindered and at first the seedlings were comparable with those in untreated soil, but they rapidly fell behind, becoming unhealthily dark in colour, and developing few tillers. After a few weeks several of the plants died and in no case was a recovery made similar to that noted with mustard sown the same day, with parallel treatment. As the fructifying period approached iodine was found to retard the development of fruiting stalks by about five days, and fewer ears were ultimately developed than in the untreated pots. The differences in maturity were hardly noticeable when the plants were harvested as they were allowed to remain uncut until practically the whole series had reached the stage of ripeness. An interesting point is that in spite of the early injury to the plants caused by iodine and although they failed to recover and looked more or less unhealthy to the end, yet the green

and dry weights of the straw and ears were very similar to those of the untreated plants, the differences being insignificant on statistical examination.

With a delay of *one week after treatment* before sowing the heavier dose of iodine proved somewhat less toxic than before, as germination was fairly good and the seedlings developed better for some time. They gradually fell behind, however, and within six weeks nearly all were dead, only a few small weakly plants struggling to maintain a hold on existence. At harvest time, when plants were dead ripe, the few remaining plants with iodine were simply bunches of green leaves with a solitary green ear in one case. The weaker dose of iodine appeared to have little harmful effect on the vegetative growth as the plants were nearly, if not quite, as good as the untreated controls. The development of fruiting stems was rather irregular and somewhat retarded, but this difference soon disappeared.

With a delay of *two weeks after treatment* a slight retarding action was still noticeable with the heavier dose of iodine, but with this exception in all the sowings the toxic effect of iodine disappeared entirely and was not replaced by any form of stimulation. The difference between the dry and green weights of the straw and ears with the different treatments on each occasion was statistically insignificant, and as all the sets were allowed to ripen before any were cut the total dry weights were very similar whatever the time of sowing (fig. 8) though the dry weights of the ears tended to be rather heavier with the earliest sowing. The considerable drop in green weight in the last sown plants is noticeable, but has no apparent significance. The reduction was entirely in the straw, the ears at the same date being quite as heavy as on previous occasions.

The percentage of nitrogen present in the straw tended to rise in the presence of iodine, whether in strong or weak doses, but no regular effect was observed in the ears, though a slight tendency towards an increase with iodine was manifest. With the control plants the nitrogen percentage increased in both shoots and ears for the first four sowings and then dropped considerably. In the shoots weak iodine caused some rise in nitrogen percentage as time went on, but strong doses gave quite irregular results. In the ears the percentage remained fairly constant with both dressing suntil the last sowing, when a distinct fall occurred (Table VI).

The actual amount of nitrogen taken up by the plants varied somewhat, but quite irregularly, both with the dressing of iodine and the date of sowing, but the amount in the iodine-treated plants was never less than in the controls and tended to be higher.

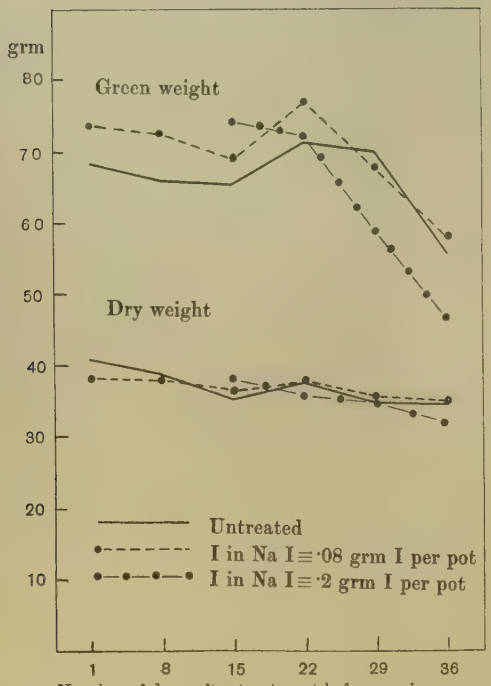

Fig. 8. Green and dry weights of barley, sown at varying periods after treatment of the soil with iodine.

Table VI. *Barley. Average of three pots.*

Treatment (iodine in grm. per pot)	1 day	1 week	2 weeks	3 weeks	4 weeks	5 weeks
			Percentage of nitrogen			
			Straw			
Control	·658	·633	·756	·857	·783	·752
0·08	·823	·816	·782	·823	·936	·911
0·20	—	1·800	·725	1·000	·890	·909
			Ears			
Control	1·64	1·70	1·99	2·00	1·92	1·66
0·08	1·76	2·03	2·08	2·15	2·22	1·65
0·20	—	—	2·00	2·21	2·03	1·86
			Nitrogen present per pot			
	grm.	grm.	grm.	grm.	grm.	grm.
Control	·428	·400	·406	·460	·406	·380
0·08	·450	·450	·428	·457	·471	·416
0·20	—	—	·441	·479	·433	·396

E. General Discussion.

The rapid loss of the effective action of iodine may be due to the element being in some way removed from the sphere of action of the plant roots. Investigations have shown that iodine is adsorbed by various substances, Scheringa(16) and other workers proving its adsorption by sand, silica, opal, agate, alumina, magnesia, beryllia and charcoal. Suzuki(19) showed that iodides are more readily absorbed by soil than chlorides. It is thus possible that part of the iodine applied to the soil may soon be rendered inactive by adsorption from solution by various constituents of the soil. This, however, would not account for the complete removal of iodine, as an adsorption equilibrium would be reached, at which point a certain concentration of iodine would be maintained in the soil solution, any iodine taken up by plants being replaced by a further supply derived from that originally adsorbed. A more probable cause of loss of iodine in its elemental state may be found in its very reactive properties and its proclivity to form addition or substitution products with various compounds occurring in the soil. Unsaturated fatty acids, such as oleic acid, can fix a number of atoms of iodine or other halogens equal to the number of hydrogen atoms necessary to saturate the molecule (Droop-Richmond(6), Grandeau(9)). It is therefore possible that if certain of these compounds occur in the soil they may unite with the iodine applied and so render it ineffective and unable to exert any influence upon plant growth. Again, iodine readily acts as a substitution element on many organic compounds of the same type as those resulting from the decomposition of organic matter in the soil, such as alcohols, ketones, aldehydes, etc., and is possibly put out of action in this way. Furthermore, interaction of iodine and alkali results in the production of iodides and hypoiodides, the latter of which have powerful oxidising properties and are unlikely to remain long as such in the soil. In the latter case the elemental iodine is rapidly converted into iodides, which would appear to have little action, judging from the fact that the plants treated with iodine in sodium iodide solution are as good as the controls when sown some time after treatment, when the conversation of iodine into iodides might be expected to be complete.

This conversion into iodide may possibly have some bearing on the failure to obtain partial sterilisation effects with iodine in spite of its great power of reaction. Sodium iodide alone appears to be inactive throughout, as indicated by figs. 5 and 6. With most of the soils tested

iodine in sodium iodide had little or no effect upon the bacterial numbers, but in one case, with soil 2, a definite increase occurred with the heavy dressing. This may conceivably mean that usually the iodine was so rapidly removed, possibly by conversion into iodide, that it had no time to exert any specific action, but that in the one case cited the removal was less rapid, and sufficient iodine was left for some time to act in the direction of partial sterilisation. This argument would also apply to the other means above indicated whereby iodine is removed from action, assuming it to be correct that iodides are inactive and the free iodine is an active agent.

In this connection it may be permissible to suggest that the great increase in bacterial numbers obtained in one instance with iodoform was due to the fact that this compound is in reality very potent although under most conditions it is rapidly put out of action, but that in the case in point its destruction was slow enough to allow time for it to exhibit a considerable degree of partial sterilisation. This is merely put forward as a suggestive hypothesis, but if it could be proved to be true, and if the conditions necessary to maintain the active power of the iodoform could be discovered, it might yet happen that iodine, in appropriate combination, could be turned to valuable account for agricultural and horticultural purposes.

It has been shown above that barley is very sensitive to the toxic action of iodine and that small doses, even after a considerable delay between treatment and sowing, fail to increase the crop in any way. Mustard, on the other hand, is more resistant to the toxic action, and strong seedlings that escape being killed by a relatively heavy dressing of iodine are apt to make rapid headway and to surpass untreated control plants both in green and dry weight, if sown at the appropriate time after treatment. This suggests that different species of plants vary in their reaction towards the element and consequently there is no justification to assume, without proof, that iodine has no beneficial action on any of the agricultural crops.

Previous work has shown that the absorption capacity for iodine of plants grown on the same soil varies to some extent with the natural order. Bourcet (2) tested a number of plants on soil containing 0·83 mg. iodine per 100 kilos soil and found that the iodine present in the plants when harvested varied from 0·00–0·94 mg. per kg., *Allium sativum* being the richest with 0·94 mg., Liliaceae and Chenopodiaceae absorbing iodine much more freely than Solanaceae and Umbelliferae. This may be compared with the work of Warington (26), who has demonstrated a

similar variable response with regard to boron, a small amount of the element being essential for the satisfactory growth of broad bean, scarlet runner and crimson clover, whereas barley, rye, vetch and pea are able to develop fully in its absence.

It has been suggested that root crops, such as mangolds and sugar beet, benefit from the use of iodine, and field experiments might profitably be carried out with these plants, especially in view of the fact that the wild beet, *Beta maritima*, is a native of the seashore where iodine is available owing to its presence in sea water. Pot experiments would be useless in these cases, owing to the large size and great individual variation of the plants.

Summary.

1. No definite evidence of partial sterilisation with iodine was obtained when a number of different soils were treated with various combinations and strengths of iodine, the bacterial numbers with different treatments varying either very little or inconsistently. A suggestion of beneficial action with iodoform was obtained, if the right conditions could be found.

2. Germination of tomato seeds in "sick" soils was not affected by treatment with iodine in sodium iodide, and the initial vigour of treated and untreated plants was very similar.

3. The loss from "damping off" of tomato seedlings was not reduced by treatment before sowing, over a wide range of concentrations of iodine in sodium iodide.

4. Germination of mustard is either inhibited or badly checked by strong doses of iodine. In the latter case some of the plants eventually make a striking recovery and ultimately surpass the untreated controls in green and dry weight. If some time elapses between treatment and sowing the toxic action of iodine disappears and the mustard is unaffected, showing neither the initial toxic effect nor the later recovery and stimulation.

5. Barley is decidedly more sensitive than mustard to the toxic action of iodine, as germination is inhibited by a smaller dressing. With an amount of iodine that allows the seeds to germinate, though checking them badly, the plants frequently die off and never make the recovery nor show the stimulation of mustard under similar circumstances. With various intervals between treatment and sowing barley is still killed off at a time of sowing and with a strength of iodine that allows mustard to make its greatest recovery.

6. The various means whereby iodine may be put out of action in the soil are discussed and the suggestion is made that iodine might

possibly have some specific and effective action if means could be found to prevent it from being converted from the elemental state so rapidly as appears usually to be the case.

7. Although no definite partial sterilisation effect has been obtained and though mustard and barley show little or no significant reaction, the possibility is not excluded that other agricultural crops, *e.g.* mangolds and sugar beet, might be benefited by the use of small amounts of iodine in addition to the usual fertilisers.

In conclusion I wish to express my thanks to Dr Bewley, Messrs Sawyer, Cutler, Thornton and Fisher for the help they have freely given in various ways during the progress of the investigations. The active assistance rendered by the Chilean Iodine Committee has already been acknowledged. I am also indebted to Mr Matthews (Shrewsbury) and Messrs H. B. and J. C. Randall (Harpenden and Waltham Cross) for supplying me with the special types of soil needed for experiment.

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NOTE ON THE ECONOMIC VALUE OF THE NEUROPTERA, WITH SPECIAL REFERENCE TO THE CONIOPTERYGIDAE

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(With Plate I.)

The order Neuroptera as now restricted is remarkably homogeneous, its uniformity being especially marked in the larval stages. The Sialidae and Raphidiidae are by some authors still included in the true Neuroptera, but it seems better to place them together in a separate order Megaloptera, of which the main distinguishing features are that in the larva the mouthparts are of ordinary biting type and the anus is functional for the voidance of excrement.

In the Neuroptera proper the larva always has mouthparts modified for piercing and sucking, formed by approximation of mandibles and maxillary lobes (? laciniae) to form hollow sucking spears; the anus is closed for the passage of solid excrement and at the end of larval life the anal papilla is used as a spinneret to construct a cocoon with silk secreted by the modified Malpighian tubes. Such larval characters appear to be without exception in Neuroptera (sens. strict.).

All known Neuropterous larvae are carnivorous, and none can be considered as pests[1]. The imagines also commonly live upon a similar diet to the larvae. The order as a whole is beneficial to man.

Up to the present time only five Neuropterous families can be said to merit notice by the economic entomologist, the remaining families, while they may to a certain extent assist in checking injurious insects, yet none are sufficiently prominent to warrant mention here. The five principal families are the Ithonidae, Coniopterygidae, Hemerobiidae, Chrysopidae, and Psychopsidae.

Of these the first and last are confined to the Southern Hemisphere and have been dealt with by Tillyard (25, 26). The larva of *Ithone* is a white, blind, Melolonthoid grub which burrows in sandy soil and preys

[1] Vuillet, J. and A. (*L'Agron. Colon.*, Paris, 1914), have suggested that Chrysopids may do more harm than good by preying upon other predacious insects, but this must be considered as an exceptional opinion.

upon the larvae of Melolonthid beetles (*Odontria* spp.(26)). *Psychopsis* has similar habits to those of *Raphidia*, and as a larva lives under the bark of trees. Its potential value in checking codlin moth larvae and the like is fully discussed by Tillyard(25).

The remaining three families are all represented in the British Isles, and as I have already dealt with the life-histories of several species elsewhere(28), descriptions of these need hardly be repeated here. The Hemerobiidae and Chrysopidae are better known than the Coniopterygidae and therefore it is to the latter family that I would give most attention in the present paper. For further details I must refer to my earlier paper.

Coniopterygidae. The Coniopterygidae have been much neglected by entomologists and are consequently regarded as being rare. Such an opinion is, however, mistaken. Several Coniopterygidae are exceedingly common, at least in England, and where they occur they are generally to be found in numbers. The larvae are small and inconspicuous—hence easily overlooked. Cocoons (Pl. I, figs. 2, 4 and 7) are no doubt frequently passed over as spider's cocoons. The imagines (Pl. I, fig. 5) might, with some excuse, be taken casually for Aleurodoids, or, when on the wing as small white moths such for instance as *Leucoptera*. Actually *Conwentzia* is one of the commonest insects in London parks on oak (*Quercus*) and plane (*Platanus*); *Semidalis* is often abundant in deciduous woods and orchards, while *Coniopteryx* is frequently plentiful in pinewoods in the south of England.

Adult Coniopterygidae differ from all other Neuroptera in their reduced wing venation and in possessing a covering of white waxy powder which is secreted and rubbed over the body of the insect shortly after emergence. They are always of small size, and because of the white powder covering them they resemble Aleurodids superficially. Structurally of course they differ materially from the latter, the most obvious differences found in Coniopterygids being the biting mouthparts, many-jointed moniliform antennae and more complex wing-venation. So far as is known at present no Coniopterygidae have less than fifteen antennal joints, and the wings have several longitudinal veins. The hindwings are reduced in the genus *Conwentzia*.

In the field, the most noticeable difference between Aleurodidae and Coniopterygidae is in the manner of holding the wings at rest. In Coniopterygidae the wings are very steeply roofed over the body (Pl. I, fig. 5), while in Aleurodidae they are much less steeply roofed and are held almost applied to the surface on which the insect is resting. A Coniopterygid when disturbed is often reluctant to fly at once and will either

run rapidly about or drop and feign death. Aleurodids take to flight more readily and have quite a different manner of walking. Once the differences in these respects have been noted the most inexperienced observer should have no difficulty in distinguishing between the two insects.

The eggs of Coniopterygidae (Pl. I, fig. 1) are laid singly, and generally at the edges of leaves. The eggs are oval, slightly flattened, with a pointed micropylar apparatus and a reticulate chorion. They average ·4 mm. to ·5 mm. in length. The incubation period varies from six days to three weeks, according to temperature.

The larva is fusiform or top-shaped (Pl. I, fig. 3), smooth or slightly hairy. The head is small, with conspicuous eyes placed laterally, and conical, sucking mouthparts. The antennae are fairly stout and easily visible, two-jointed. The thorax is the broadest part of the body, as a rule, and the legs borne by it are well developed, with the usual Neuropterous unjointed tarsus, two tarsal claws and a small empodium. The abdomen consists of ten segments tapering to the anal extremity. It is often very little longer than the thorax. The length of larva when full fed is from 2 mm. to 3·5 mm.

After two moults, and in from two and a half to four weeks in summer, the larva spins a flat circular cocoon (Pl. I, figs. 2, 4 and 7) of white silk, using its eversible anal papilla as a spinneret. In the case of the first brood cocoons are spun either upon leaves or trunks of trees, but the second brood, which is to hibernate, spins entirely on the trunk. A more or less double cocoon is constructed, but often the inner envelope is imperfect. *Coniopteryx cerata* Hagen, a Ceylon species, spins a most beautiful cocoon with pleats or folds radiating from the centre.

The larvae pupates in a few days in summer and the imago appears about a fortnight after spinning. In the case of the overwintering brood the larva does not pupate, but rests as a prepupa within the cocoon. In spring pupation and emergence occur. The emerging pupa bites a semicircular slit through the cocoon, and the imago escapes from the pupal skin. After the wings have dried, the waxy powder secreted upon the body is scraped off by the hind legs, and, at intervals, is rubbed over and between the wings.

The male imagines of Coniopterygidae are alone attracted to lights at night, the females apparently not being positively phototactic. The imagines feed on similar food to the larvae, but seem to prefer semi-liquid sweet matter, such as honeydew.

The larvae are predaceous upon mites, small Rhynchota, etc. I have never seen a full-grown aphid of medium size attacked. *Conwentzia*

psociformis larvae, for instance, will prey upon young nymphs of *Vacuna dryophila* Westw., and they feed largely on such in nature, but I have not been able to induce one to take a full grown *Vacuna*.

On the oaks in England the main check upon *Phylloxera punctata* Licht., is frequently *Conwentzia psociformis* Curt. In many parts the damage done to the foliage of oaks by *Phylloxera* is considerable, and some trees seem hardly able to survive the combined attacks of *Tortrix viridana* and of *Phylloxera*. The value of the beneficial work of *Conwentzia* is well testified by the great numbers of cocoons of this insect which may often be seen upon oak trunks during the summer (Pl. I, figs. 4 and 7).

Not only may *Conwentzia* be found preying naturally upon small Rhynchota, but the oak "red spider" (*Paratetranychus quercinus* Berl.) and other mites must be counted among its common hosts. This fact suggested that possibly *Conwentzia* might with benefit be artificially established upon trees infected with common red spider (*Tetranychus telarius* L.). The ideal employment of *Conwentzia* in England would be in such as peach houses, where I feel sure that the Coniopterygid would prove its worth, especially if its parasite *Lygocerus* could be excluded. I am indebted to Professor Lefroy for his efforts to induce certain growers to give this experiment a trial, but none could be persuaded to forego fumigation with nicotine, which of course would prove fatal to *Conwentzia*. I therefore have had to content myself with tests in the open. Various fruit trees infected with mites (*Tetranychus telarius* L., on grape vine; *Bryobia praetiosa* K., on pear and gooseberry; and an unidentified Orobatid on apple) were selected in a neighbourhood where *Conwentzia* had not been previously observed. Cocoons or imagines of the Coniopterygid were placed on the trees. In each case marked success followed. The mites were greatly reduced in numbers and the *Conwentzia* thrived, but every time the parasite *Lygocerus* made its appearance in the second year to the detriment of *Conwentzia*.

The following example may be taken in illustration. A pear tree badly infected with *Bryobia praetiosa* K. was selected, and six newly emerged *C. psociformis* imagines were set free upon the trunk on the 10th May, 1921. From the 15th to the 26th June, 1921, twenty cocoons were counted upon the trunk, and probably more were present on leaves and twigs. By the 8th July more cocoons had appeared. On the 20th July over one hundred cocoons were counted on the pear trunk, thirty on another contiguous pear, and six on an apple. On the latter tree the most probable food for *Conwentzia* observed was young migrating *Eriosoma lanigerum* Hausm., and a few Psocids. About 30 per cent. of

the cocoons of the 20th July did not yield imagines in 1921 but hibernated along with the true second brood. There were quite possibly many second brood cocoons among these and one could not say definitely under such conditions of observation. Between the 27th July and the 4th August imagines escaped from the greater part of 70 per cent. of the cocoons. These empty cocoons were then removed in order to make a fresh count of the true second brood. The second and last brood of the year were spinning up in large numbers on the 14th August. Larvae continued spinning in decreasing numbers into September. It was now seen that six or seven neighbouring pear trees also bore numbers of *Conwentzia* cocoons. An exact count could not be made, but it would doubtless have exceeded one thousand cocoons.

In September and October the cocoons were observed to be attacked by larvae of *Chrysopa tenella* Schn., which pierced the cocoons with their jaws and sucked out the juices of the contained larvae. In July 1922 a single parasite *Lygocerus* was noticed on the bark of the pear. The second brood of *Conwentzia* was much smaller than that of 1921. It was found to be heavily parasitised by *Lygocerus*, and a further reason for the reduced numbers was the fact that no specimens of its previous food, *Bryobia praetiosa* K., were now to be found. It seems quite clear that *Conwentzia* was largely responsible for the disappearance of the mite.

From this experiment alone, and similar cases could be quoted, it seems clearly possible to employ *Conwentzia* as a check upon various pests, especially against such as red spider. Given favourable conditions and absence of parasites I consider that there are unusual possibilities with *Conwentzia psociformis*. Such conditions would probably be obtained in England under glass. It is decidedly unfortunate that this has not been put to the test and that there is no positive evidence to offer. However, the suggestion is put forward and it is hoped that some future worker on this family will make the experiment, which, if inferences can be drawn from outdoor results, should prove highly successful. Probably *Conwentzia* would also prove efficient in other countries where the genus does not exist if it can be introduced there without its parasites.

The following method of establishment might be tried. To avoid the parasite *Lygocerus* collect larvae of *Conwentzia psociformis* when they swarm on the oak trunks in August[1]. Transfer these to a box with corrugated paper, or the like, upon which they will readily spin. Thus they can easily be handled and packed. *Lygocerus* attacks the cocoon

[1] July or September in some years.

and bites a hole in it to deposit an egg, therefore collection of larvae before spinning should exclude this parasite. There are other parasites to be expected, however. Should the *Conwentzia* larvae not be taken when they are about to spin, only such cocoons should be collected as appear unperforated. These are more likely to have been untouched by *Lygocerus*, but there is still a risk.

Chilling, as in winter, appears to be necessary before the second brood larvae (prepupae) will pupate, so that for shipping no special precautions seem to be indicated to prevent emergence *en route*. This, however, requires to be further tested.

One dozen cocoons attached to the bark of a tree should be sufficient to start a colony. The emerging insects do not fly readily and will, if food is present, usually remain on the tree to which transferred. Thus pairing and egg laying should certainly follow. It is far better, however, to place newly emerged imagines and not cocoons on the trees if there is the slightest possibility of any cocoons being parasitised. This is bound to be the case with wild cocoons.

In introducing Coniopterygidae to a foreign country parasites must be rigidly guarded against. Up to the present two Chalcid parasites of *Conwentzia psociformis* have been found. The life histories of these have not yet been fully worked out, but both have been bred from cocoons. *Lygocerus* sp. tears a hole in the cocoon of *Conwentzia psociformis* in late summer or autumn and then lays one egg within. The parasite larva (Pl. I, fig. 8) is full fed before winter and it pupates in early summer of next year. In July the adult parasite appears and the cycle probably recommences. Thus it would seem that *Lygocerus* is single brooded, but I have some observations of a possible double brood.

A little experience will enable one to detect the full fed larva of *Lygocerus* within a *Conwentzia* cocoon in winter. It is only necessary to remove the outer envelope of the cocoon when the orange-pink parasite larva will be seen within. Usually the small hole torn in the envelope by the parent *Lygocerus* is distinctly visible from outside, but parasitised cocoons have been found in which a hole had not previously been detected. The best way to avoid *Lygocerus* is to collect full-fed larvae of *Conwentzia* just before spinning and allow them to spin in captivity.

A second parasite, *Ceraphron* sp., has emerged from cocoons of *Conwentzia psociformis* during July and August. Two females came from each of eleven cocoons. I know very little of the life history of this species and therefore can advise no preventive measures.

A great drawback to the introduction of Coniopterygids into greenhouses is that growers may confuse them with Aleurodids. In the case of *Conwentzia* this confusion need hardly occur as this insect is much larger than *Aleurodes vaporariorum* and once the two insects have been compared in life a person with no scientific training should at once be able to distinguish between them. It has already been pointed out that the manner of holding the wings at rest, antennae, etc., are totally different.

In giving attention to the Coniopterygidae it is desired to point out that there appear to be potentialities in this Neuropterous family which have been overlooked and a trial of the foregoing suggestions seems well worth while. The writer is not in a position to continue this work at present and the evidence so far obtained is insufficient, but all results, as far as they have gone, have been highly satisfactory and there seem to be considerable possibilities. The Coniopterygidae, but more especially those species of the genus *Conwentzia*, appear to lend themselves well for experiment. They are semi-gregarious and fly little, thus they tend to become abundant locally and do not leave one plant until scarcity of food compels. Each female lays a fair number of eggs, probably about two hundred in nature, as it continues to live and feed for a month or so. The cocoons are conspicuous, being spun in the open, and they can thus be easily collected and distributed. The one necessary precaution is against the introduction of parasites with the cocoons. Apparently the larva itself is not parasitised while free, but this assertion must not be taken as necessarily without exception.

In America notices of *Conwentzia hagani* Bks., preying upon red spider (*Tetranychus telarius* L.) and other mites damaging fruit trees (citrus and cherry) have appeared by Quayle (19, 20) and Houser (12). This species seems to be very similar in habits to our *Conwentzia psociformis* Curt.

Hemerobiidae. The Hemerobiidae as a whole seem to prefer trees to low-growing plants. They are therefore found mainly in woods and forests. In the south of England the commonest species in orchards and gardens is *Boriomyia subnebulosa* Steph. This insect is often found as a larva on low herbs.

The egg is attached by its side to the undersides of leaves of plants, also concealed in crevices, etc. It is elongate oval in shape, smooth, but with the chorion finely pitted, as a rule. There is a micropylar knob more or less distinct. In length eggs vary from ·4 mm. to 1 mm. Colour at first is generally white or yellowish-white. The incubation period in summer varies from six days to two weeks.

The larva in the first instar alone has a trumpet-shaped empodium between the tarsal claws. In later life this is reduced to a small and inconspicuous pad. A Hemerobiid larva can thus be distinguished from a Chrysopid by the absence of the trumpet form of empodium in later life. Other characters of the Hemerobiidae are the shorter, stouter jaws, and the long, fusiform and almost nude body. The body of the Hemerobiid larva never bears setigerous tubercles and never in consequence carries rubbish upon the back. Larvae when full-fed vary from 4 mm. to 1 cm. or more in length. The active larval period in summer averages ten to fourteen days.

The cocoon is spun among leaves or in a crevice of bark, etc. It is oval in shape and of fairly open mesh so that the insect can usually be seen within.

The life cycle varies considerably. There may be one or many generations in a year. Winter is passed in all stages, according to species.

The British species vary too greatly in their feeding habits to enable one to assign any species to particular trees. The following with their preferences are given as a guide, in case it should be desirable at any future date to employ Hemerobiids against special pests.

Conifers. *Sympherobius inconspicuus* McL., *Hemerobius nitidulus* Fab., *H. orotypus* Wallengr., *H. stigma* Steph., *H. pini* Steph., *H. limbatellus* Zett., *H. atrifrons* McL., *H. mortoni* McL., *Boriomyia rava* Withyc., *B. concinna* Steph., *B. quadrifasciata* Reut.

Deciduous Trees. *Sympherobius pygmaeus* Ramb. (oak), *S. elegans* Steph. (beech), *Hemerobius micans* Oliv. (beech), *H. humuli* L. (oak, beech, hazel, etc.), *H. lutescens* Fab. (oak, beech, hazel, etc.), *Boriomyia subnebulosa* Steph. (various), *B. nervosa* Fab. (birch, etc.), *Micromus paganus* L. (low herbage).

Of this list the most common species may be taken as *H. stigma* Steph., in pinewoods, and *B. subnebulosa* Steph., everywhere. The latter species is very common in gardens near London and may be easily obtained at light. The larva often feeds on *Aphis rumicis* L., on broad beans and is also found commonly upon apple trees, but it is not at all particular as to diet.

In America we find *Sympherobius angustus* Bks., recorded by Essig(3) as feeding upon the citrus mealy bug (*Pseudococcus citri*) in California. *Hemerobius californicus* is noted by Quayle(20) as preying upon red spider. Other records are given in the bibliography.

Chrysopidae. The Chrysopidae or Green Lacewings are well known,

and their value in checking aphids in gardens and orchards need not be expatiated upon.

The eggs, which are usually a little less than 1 mm. long, are of long oval shape, smooth, and with a saucer-shaped micropylar apparatus. The colour is generally greenish. The antimicropylar pole is attached by a hair-like stalk to a leaf or twig. The stalk varies in length from about 2 mm. to 9 mm. Eggs are laid singly, in spaced clusters, or in dense clusters with stalks united into a bundle. The number of eggs laid by a single female varies from one to several hundred. (I have obtained four hundred eggs from a female of *Chrysopa phyllochroma*.) The period of incubation averages just over a week in summer, but varies according to temperature.

The larva is stouter in build than most Hemerobiidae. It is also generally much more hairy, and in most species the larvae have tubercles from which arise tufts or brushes of stiff hairs. The empodium between the tarsal claws is trumpet-shaped throughout life. The larval period averages about three weeks in England.

For pupation a closely woven, parchment-like oval cocoon of silk is spun among leaves or under bark, etc. Winter is generally passed as a prepupa, but sometimes as a larva or imago.

To conifers *Chrysopa dorsalis* Burm., and *Nothochrysa capitata* Fab., are especially attached, but *C. vulgaris* Schn., *C. flavifrons* Br., *C. prasina* Burm., *C. ventralis* Curt., and *C. perla* L., are also commonly to be met with in pinewoods. *C. prasina*, in particular, is most often found feeding upon *Chermes* in young pine plantations.

On deciduous trees one may find *Chrysopa flava* Scop. (oak, beech, hazel, sycamore), *C. vittata* Wesm. (oak, beech, hazel), *C. vulgaris* Schn. (various trees and shrubs), *Chrysopa tenella* Schn. (various trees and shrubs), *C. alba* L. (shady woods), *C. flavifrons* Br. (various trees and shrubs), *C. prasina* Burm. (oak and beech), *C. ventralis* Curt. (oak and beech), *C. septempunctata* Wesm. (gardens and orchards), *C. perla* L. (low woodland and hedges), *C. phyllochroma* Wesm. (bean-fields).

As most important of these may be selected *Chrysopa prasina*, *C. flava*, *C. vulgaris*, *C. tenella*, *C. septempunctata* and *C. phyllochroma*.

C. prasina as a larva is undoubtedly a valuable check upon *Chermes* in young pine plantations. It is one of the very few predaceous insects which will attack this aphid and its activities continue throughout the winter. The larvae may be found, concealed by the dense packet of aphid wool and skins upon their backs, crawling over the trunks of the trees during any warm spell of the winter months. In summer larvae can be

beaten from the branches. Similar remarks will apply to *C. ventralis* and *C. flavifrons* but these two species are usually less common. The larvae of all three species will live for weeks without food if kept at a temperature between 32° F., and 40° F.

C. flava is a species which seems to prefer larger Aphids, Psyllids and Jassids in its larval state and I have sometimes failed to keep larvae at all on aphids such as *Aphis rumicis* L., and *Aphis* (*Brevicoryne*) *brassicae* L. Although extremely voracious, attacking even spiders and beetles in nature, it is curious that at times the larvae should prove so delicate in captivity. The species seems to be especially attached to oaks.

C. vulgaris is not common in England as a rule. The larva is almost omnivorous as far as small insects and mites are concerned. In the continent of Europe and throughout all the Mediterranean region it is abundant, judging by the frequency with which it appears in collections. From France it is commonly reported (2, 7, 8, 9) upon grape vines where it preys upon larvae of *Polychrosis botrana*, *Phylloxera* and red spider. Imagines are frequently caught in sugar traps set for *Polychrosis*. *Chrysopa vulgaris* hibernates as an imago.

The larvae of *Chrysopa tenella* and *C. septempunctata* may be given mention as feeding upon *Eriosoma lanigerum* Hausm., on apple. So few natural enemies of apple woolly aphis are known that this is worth noting. In tastes both species are not at all fastidious and many other orchard and garden insects are also preyed upon. *C. septempunctata*, for instance, is a common check upon *Aphis rumicis* L., on beans. Both *C. tenella* and *C. septempunctata* hibernate as prepupae within the cocoon.

Chrysopa phyllochroma, Mr B. S. Harwood tells me, is often found by him in bean-fields, where its probable food is *Aphis rumicis*. Mr Harwood sent me one female of this species from which over four hundred eggs were obtained. Both imago and larvae fed readily and thrived upon *Aphis rumicis*. The larva can be described as somewhat like a slightly elongate *C. tenella* larva in general appearance, the colour being grey, but there are several differences in detail which will be described in a subsequent paper.

In America the principal papers dealing with Chrysopids from an economic standpoint are those of Wildermuth (27) and Smith (21, 22). The former gives the life history of *Chrysopa californica* Coq., and includes a list of host insects comprising mites, Jassids, Psyllids, Aphids and Coccids. Smith (22) has given a very complete account of the life histories of several American Chrysopids and to his excellent paper reference should be made.

In Australia Chrysopids are mentioned as preying upon Aphids (11) and Coccids (10).

In this paper it has been my endeavour to give only such details as are likely to be of value in the selection and naturalisation of Neuroptera for economic purposes. Details of the insect's length of life, fecundity, food, etc., are omitted not because they are unimportant but because there is such great variation that without much more complete evidence, under greater variety of conditions, such details might convey erroneous impressions. Personally I have only been able to observe the British species near London, and under consequent very limited environmental conditions. Where preference in food is assigned to certain species this is always from observations in the field and not in captivity.

As regards the amount of food taken, a brief mention of this was given in my recent biological paper (28). In adopting a standard size aphid as food throughout, and in compelling even the first instar larvae to feed upon such aphids, a much smaller total of aphids eaten during life was obtained than that of most previous observers. Of course in nature a newly hatched larva would for preference attack aphids smaller than itself at first, but in my experiments this preference was repressed. If the larva is given smaller aphids at first it is natural to expect that a larger figure for the total number of aphids eaten will be obtained. For further details of amount of food taken by Neuropterous larvae see Quayle (19) for Coniopterygidae, Quayle (20) for Hemerobiidae, Wildermuth (27) for Chrysopidae.

The parasites attacking Neuroptera have been also omitted here except in Coniopterygidae. There is still much to be learned concerning these and a preliminary list of British parasites has already been given (28). Others have since been found. In Chrysopidae Hymenopterous parasites attack eggs, larvae, and prepupae. The imago alone can be considered free, and this only in the absence of evidence to the contrary.

The present paper is merely offered to fill certain gaps in the literature and to suggest promising lines for future investigation. It is hoped that the facts here reviewed may be of assistance to the economic entomologist.

Summary.

1. The Neuroptera as a whole are distinctly beneficial to man. Three families of economic importance are represented in Britain; the Coniopterygidae, Hemerobiidae, and Chrysopidae.

2. The Coniopterygidae are far more common in England than is

generally supposed. In general facies they resemble Aleurodidae, but can easily be distinguished.

3. The eggs are laid generally at the edges of leaves. Larvae are top-shaped, with small head and mouthparts. They are predacious. After two moults a flat, circular cocoon is spun.

4. Larvae of *Conwentzia* are very beneficial on oaks in England, where they prey upon small Rhynchota, such as *Phylloxera*, and mites.

5. They would seem to lend themselves particularly well to employment economically and might be introduced to peach houses in England.

6. Six imagines of *Conwentzia* released upon a pear tree infected with *Bryobia praetiosa* K., resulted in roughly one thousand individual cocoons at the end of the season 1921.

7. *Conwentzia* could probably be introduced successfully into other countries where the genus does not exist. Parasites must be rigidly guarded against.

8. The Hemerobiidae are more often found in woods than elsewhere in Britain. Some shew preference to conifers, others to deciduous trees. *Boriomyia subnebulosa* Steph. is common in orchards and gardens near London.

9. The larvae of Chrysopidae differ from Hemerobiidae by possessing throughout life a trumpet-shaped empodium, and generally setigerous tubercles.

10. As in Hemerobiidae, larvae, according to species, shew preferences to different trees.

11. *Chrysopa prasina* Burm. is a valuable check upon *Chermes*, on conifers; *C. tenella* Schn., and *C. septempunctata* Wesm., on *Eriosoma lanigerum* Hausm., of apple; while *C. phyllochroma* Wesm., probably does valuable work in bean-fields in some parts.

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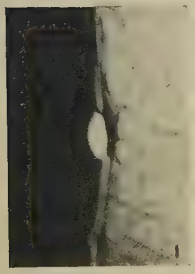

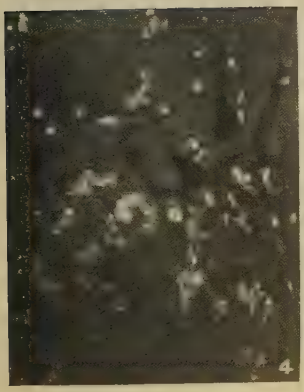

WITHYCOMBE.—Note on the Economic Value of the Neuroptera, with Special Reference to the Coniopterygidae.

EXPLANATION OF PLATE I

Conwentzia psociformis Curtis

Fig. 1. Egg of *Conwentzia psociformis* Curt., on edge of oak leaf, underside. (×12.)
Fig. 2. Parasitised cocoon of *Conwentzia psociformis* Curt., on oak leaf. (×1.)
Fig. 3. Full fed larva of *Conwentzia psociformis* Curt. (×4.)
Fig. 4. Cocoons of *Conwentzia psociformis* Curt., on bark of oak tree. A portion of Fig. 7 to a larger scale.
Fig. 5. *Conwentzia psociformis* Curt., imago. (×4.)
Fig. 6. Pupa of *Conwentzia psociformis* Curt., removed from cocoon. (×12 approx.)
Fig. 7. Cocoons of *Conwentzia psociformis* Curt., on trunk of an oak tree in Epping Forest.
Fig. 8. Parasite (*Lygocerus* sp.) larva full fed. Cocoon opened in winter. (×4.)

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A NOTE ON CUTWORM BAIT EXPERIMENTS

By WILLIAM C. COOK.

Bozeman, Montana, U.S.A.

There appeared in this *Journal* for July, 1923, an article by Fryer and Stenton(1) in which experimental data were presented showing the development of four laboratory methods of determining the attractiveness of cutworm baits. The writer of this note has been occupied with cutworm studies for several years, and, while working at the Minnesota Agricultural Experiment Station, developed a method for such experiments quite similar to the unsuccessful technique of Fryer and Stenton in their "Series I," but which has proved uniformly successful, and may be of interest to readers of this *Journal*.

The method followed, which was undoubtedly suggested by some experiments of Dr R. N. Chapman(2) on the selection of food by *Tribolium confusum*, was to liberate a given number of larvae in the centre of a circle, around whose circumference were placed alternating piles of two unpoisoned baits to be tested. In practice, sixteen piles of the baits, spaced evenly around the periphery of a circle two feet in diameter, were found to be a sufficient number to give good results. The cage was darkened and record was made of the number of larvae feeding on each bait after a half hour or so.

It was found necessary to place each pile of bait on a paper, and to place a pile of loose sand in the centre of the circle to eliminate such larvae (usually nearly half of the total number) as were seeking shelter and not food.

This method has proved entirely reliable and repetitions of a given test with several different lots of larvae of the same species and age have always given very nearly identical results.

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REVIEWS

Botanical Pen-Portraits. By J. W. Moll and Dr H. H. Janssonius. Martinus Nijhoff. The Hague. 1923. 30 Gld.

This is an astonishing volume and something quite new in botanical literature. It is a minute description of the macroscopic and microscopic anatomical characters of one hundred or so common drugs and is a large well packed volume. Anatomical descriptions are, as a rule, dull enough reading, but these compel one's interest: the fullness of detail is a thing never before attempted and one is left gasping with the feeling that this knowledge is complete and final. In a long preface which is really a very fascinating essay written apparently by Dr Moll, the general history of descriptive method in pharmaceutical botany is briefly sketched leading up to an account of the micrographic method of the present volume. In reading this delightful essay it is interesting to find one's mind constantly reverting to de Candolle's 'Phytographie' and one is astonished to find how far sighted and modern many of his views were. In very largely abandoning illustration by line drawings and in elaborating their method of pen-portraiture which is in essence minutely accurate, quantitative, and perfectly systematised three-dimensional description, the authors have made a very important advance in pharmaceutical diagnostics.

Following the preface are some twenty pages of 'Guiding Schemes' which are minutely analysed key-schedules for guidance in writing pen-portraits of any particular structure. These schemes are very completely worked out and should prove of very considerable service in systematising anatomical description in general phanerogamic botany quite apart from their use in pharmaceutical studies. In any system of pen-portraiture rigid schedules such as these are obviously essential. The authors' schemes are the fruits of long years of experience and a rare capacity for taking pains and as guiding schedules seem almost perfect of their kind.

The book itself is a series of examples of the use of the guiding schemes applied to various common drugs. In the arrangement of the pen-portraits the authors have made a very sensible and long-overdue departure from common pharmaceutical practice. In the ordinary Pharmacopoeias the name of the plant from which the drug is obtained precedes the morphological structure in which it is found, e.g., *Coriandri Fructus, Hydrastis Rhizoma* and so forth, and in this way the drugs are scattered over the pages in a totally irrational and very inconvenient way. In the present work the much more logical and useful sequence is adopted of transposing the binomial names, grouping together the drugs from homologous plant organs and within each group arranging the plant names alphabetically. In this way for example *Lignum Guaiaci* is followed by *Lignum Quassiae* and not by some rhizome or leaf drug from a totally unrelated plant whose name chances to begin with the letter G.

The pen-portraits are in themselves of considerable interest and shew what can be accomplished by the micrographic method when backed by almost superhuman patience and industry. One of the most striking and valuable aspects of the portraits is the way in which quantitative methods have been used. In 1919 MacLeod published a book on *Quantitative Method in Biology* which has been far too much overlooked in anatomical, pharmaceutical and other lines of research in which the application of many of the quantitative methods discussed by MacLeod are vitally applicable. Moll and Janssonius apparently unacquainted with MacLeod's work have yet applied quantitative method in many of their micrographic studies and their valuable results take one an appreciable step towards the ideal of the reduction of anatomical diagnoses to a numerical formula.

The only book in any way comparable with the present one which the reviewer has actually used with any degree of laboratory intimacy is the Oxford translation by Boodle and Fritsch of Solereder's great work on the *Systematic Anatomy of*

Dicotyledons. In this, very different descriptive methods are followed and it is only by comparison with such a treatise that one realises the advance in accuracy and precision and completeness of description which Moll and Janssonius have attained in their work.

In addition to the contents already mentioned the volume contains a complete list of reagents used in the pharmaceutical examination of drugs, a very full and useful bibliography, a glossary and a good index. The book is one which will interest all anatomists and students of pharmacy and which will be of the utmost service to research workers attempting anatomical descriptive work. Moll and Janssonius have in fact set a new and much higher standard in botanical description. The volume is written in English and beautifully produced, but its pages contain too many misprints.

WM. B. BRIERLEY.

Diseases of Crop Plants in the Lesser Antilles. By WILLIAM NOWELL, D.I.C. (West Indian Committee, 14 Trinity Square, London, 1923. 12*s*. 6*d*.)

The attention of English speaking peoples was first called to diseases of tropical crops when the coffee industry in Ceylon was destroyed by *Hemeleia vastatrix*. Even a disaster of this magnitude failed to bring home to the minds of tropical agriculturists the vital importance of plant diseases as a limiting factor in crop production and the progress of knowledge was very slow. In the succeeding years a few special treatises were published such as Watt's *Pests and Blights of the Tea Plant* and Wakker and Went's *De ziekten van het Suikerriet* both in 1898 and from time to time smaller brochures dealing with specific troubles. Only in 1911 appeared the first general compendium, *Maladies des Plantes Cultivées dans les Pays Chauds*, by Delacroix and Maublanc and this was followed in 1913 by *Diseases of Tropical Plants* by M. T. Cook the American plant pathologist. Since then no comprehensive and general account of tropical diseases has been published but special treatises such as those of Petch on *Diseases of the Tea Bush* and *Diseases and Pests of the Rubber Tree* have appeared. In 1918 Butler set a new standard by the issue of his *Fungi and Disease in Plants*. This is a masterly survey of diseases of field and plantation crops in India and incidentally a very remarkable book consisting as it does very largely of the personal work of the author and his colleagues. The fine example set by Butler has been followed by Nowell of the West Indian Department of Agriculture who has just published a treatise on *The Diseases of Crop Plants in the Lesser Antilles*.

In many ways the latter volume invites comparison with Butler's volume. Both are written by research men having very special and intimate knowledge of the particular crops in the areas with which they deal and both write with a ripe experience of their problems. Both books are based essentially on the same plan—a first part dealing with the nature of fungi, their food requirements and life histories, the causation of disease and the principles and methods of disease control; followed by a second part containing an almost monographic treatment of diseases of special crops, many of which are common to both areas.

The Lesser Antilles are of course microscopic compared with India and it is almost inevitable that this difference should be reflected in the two volumes. Nowell's effort, admirable though it be, is perhaps a little parochial compared with the wider vision and grasp of Butler's volume. Still that is no detriment in a volume written primarily for parochial purposes and that one should compare it with Butler's work is in itself to give it high praise.

Concerning volumes such as these one may hazard a remark with which perhaps there may be much disagreement. The distinctive part of such works is the consideration of the diseases of the special crops in the particular areas. The introductory parts dealing with fungi and disease in general are not obligatorily related to the special parts and in these two volumes might almost be interchangeable or have been published entirely separately. In the early volume by Delacroix and Maublanc the general part occupies about one-half the work; in that by Cook about one-quarter, in Butler's volume about the same and in Nowell's about one-third. The two latter volumes will it is hoped be followed by others from mycologists in various Overseas

Dominions but one may perhaps suggest that unless the authors have some definite contribution to make to the general theory of plant disease or some new interpretation or improved arrangement which demands expression, there is no obligation on them to occupy a large part of their volumes with general introductory matter. For this, they can refer to Butler, Nowell or even general text-books and confine themselves to their own special subject which is their real contribution.

One of the most welcome and promising signs in plant pathology to-day is the marked tendency for the plant pathologist to get away from the domination of academic mycology, a fetter which tradition has placed upon him and which is in no way more vital to his work than physiology and agriculture including soil physics and chemistry. Nowell's attitude is very sane. He says: "As a result of personal experience of which the whole tendency has been to compel a mycologist to become an agriculturist the writer is convinced of the need for a broad treatment of his subject. The mycologist is most concerned with the fungus, the pathologist with the disease, and the agriculturist with the crop, but a combined view of the interests of all three is necessary for the production of an economic plant pathology."

It is impossible in this review to discuss critically the mass of information in Nowell's volume. Many of the problems considered are still *sub judice* and the author takes a wise and discreet middle course stating in a very fair way the conflicting opinions and evidence.

The West Indian Department of Agriculture has reason to be proud of its mycological staff for the work under review is to a very large extent built up on the author's own observations supplemented by those of Howard, Lewton Brain, Stockdale and South, predecessors in his post. The work is illustrated by text-figures and many beautiful photographs but there are one or two of the latter which might with advantage be brought up to the general standard. Figure 109 is not good and the poor reproduction of Engler and Prantl's very inadequate Pflanzenfamilien picture of Corn Smut in figure 99 does very scant justice to the appearance of this disease in the field. A good photograph from nature would be a decided improvement. Text-figure 1, reproduced again in text-figure 124 as "*Thielaviopsis* in Cells of Sugar-Cane" is distinctly crude. The author apologises for his bibliography and it really is a pity that he did not ask a friendly colleague to complete it for him for it is a serious lapse in a very fine piece of work.

The volume is published on behalf of the Imperial Department of Agriculture by the West India Committee and one can only congratulate the authorities concerned on the wisdom of their action and on their good fortune in having Nowell to prepare the text. It only remains to add that the volume contains a justly appreciative foreword by Professor Farmer, that it is very sensibly produced (which cannot be said of certain recent botanical volumes!) is commendably free from misprints and has the very great virtue of being issued at 12*s.* 6*d.* It is a volume that will be invaluable to all students and practitioners of tropical agriculture in West Indian and similar areas and one that all technical plant-pathologists will find a very useful addition to their library.

WM. B. BRIERLEY.

The Principles of Insect Control. By ROBERT A. WARDLE, M.Sc. and PHILIP BUCKLE, M.Sc. (Manchester University Press: Longmans Green.) 20*s.* net.

The literature devoted to Economic Entomology during the last twenty or thirty years is enormous. It is scattered throughout Agricultural, Medical and other publications; it is often buried in obscure journals and Experiment Station bulletins, and much is therefore inaccessible to many workers of this branch of science and hardly available at all to the practical man. The labour involved in collecting so much material and in giving a just review of it would have daunted most men, yet this has been adequately accomplished by the authors. Moreover this modern entomological warfare is no longer a question of small skirmishes and rule of thumb methods, of occasional battles and retirement to winter quarters. So intimate are the relationships of insect life to the well-being, both physical and economic, of mankind that it

demands the unceasing vigilance of a considerable army of highly trained men in every civilised country, who apply almost every type of scientific knowledge to the prosecution of their campaign. Biology, chemistry, physics, meteorology, engineering, have contributed and each year do so on an increasing scale to our knowledge of the best ways and means of combating insect attack. This book may well be regarded as a War-book; it is an attempt to coordinate within a limited scope all the intricate and complicated strategy so far elaborated for this purpose.

It is impossible in a short review to survey even in the briefest detail the mass of material gathered together here. The authors divide their subject into four parts dealing with the methods employed in Biological, Chemical, Mechanical and Legislative Control. The first three of these are further sub-divided into theses which deal in brief detail with the fundamental principles involved and with the practical means of applying them. It is of course obvious that such a treatment is in some measure artificial. For example a good proportion of the matter dealing with mechanical control by 'baits and traps' and in 'crop storage' is largely chemical in essentials, and 'cultural methods' are not necessarily merely mechanical. Such treatment however despite its somewhat illogical nature does enable one to pigeon-hole a complicated mass of fact. It is also obvious that a book of this type must be a compilation and an expert would be needed to deal completely with each of the chapters. Yet these are not disjointed digests of work done in many fields, but are linked together and welded, where possible, into a complete story, with a word or two of shrewd criticism sprinkled here and there.

Perhaps the one unsatisfactory chapter in the book to the reviewer is that dealing with Parasites and Predators. To the non-specialist reader who depends upon digests of the literature of this type for his general information, it would appear too condensed to be clear while for the expert it is probably too scanty for purposes of reference.

The chapters dealing with Insecticides are quite admirable. Criticism can only be levelled at minor points. Shafer's fundamental work might have been described in greater detail, and it is to be hoped that those readers who carefully peruse the excellent bibliography attached will turn up the original account of his researches. But on the whole the present state of our knowledge about the fundamentals of insecticidal action are well reviewed. It is admitted by all that it is still very incomplete and there is probably much set down here that will have to be revised later in detail. For example our information as to how insecticides penetrate the chitin, is still lamentably small, and it is probable that gases and vapours have a different mode of action from liquids and solids. The authors indicate one important essential, that solids must fulfil, if they are to be used as insecticides—they must be finely dispersed; this not only because powders tend to settle more rapidly and to clog nozzles but because toxic intensity would appear to depend directly upon fineness of division.

On page 74 there is an error in the equation dealing with 'the poison exponent' of insecticides, while on page 125 in the account given of Facer's method of analysing tank fluids, a very precise chemist would probably prefer the term arsenious to arsenic oxide. These are small matters but the statement occurring on page 197, dealing with the toxicity of chloropicrin to human beings might have grave consequences. It needs the clearest recognition that chloropicrin may be highly poisonous to some individuals and should never be applied by an operator unprotected by a good box gas-mask.

This book however is packed tight with all kinds of useful information, and not the least valuable parts are those devoted to words of warning about undesirable methods, built up on inadequate knowledge and which may more than defeat their purpose.

There are good descriptions and illustrations of machinery, and a great number of formulae are given for insecticides and baits. A *sine qua non* for a book of this type —a good index—is included. The authors express some diffidence as to the arrangement of their material but bearing in mind the complicated way in which the subjects in reality dovetail into each other, it is a matter of surprise to see what an orderly array they have made of what must have seemed unrelieved chaos when they began

their task. It is inevitable of course in a résumé of this type that the specialist should find things to criticise in the chapters dealing with his field of work: there are bound to be some small errors of detail, errors of stress and of omission. The particular value however of the book is that it will enable the specialist to link up his own branch with others and to draw upon them for new ideas. To the beginner it will not only afford an insight into the methods employed, but should offer him much inspiration in indicating how broad is the field, and how much remains still to be done, while to the general economic entomologist it will prove a very readable text-book and a handy book of reference.

F. TATTERSFIELD.

Diseases of Greenhouse Plants. By W. F. Bewley, D.Sc. Ernest Benn, Ltd., 1923, pp. 208, figs. 47. Price 12*s.* 6*d.*

A text-book on plant pathology should cover the ground embraced by the three main branches of the subject, namely diagnosis, aetiology and therapeutics. Viewing plant-pathology as an applied science the most important branch is the last named, since the very *raison d'être* of the science lies in its ability to control plant-disease. Inasmuch as any satisfactory method of control is necessarily based on a thorough understanding, not only of the host-plant and the parasitic organism, but also of the inter-relationships of the two, it is not surprising that this aspect of the science has been the latest to be developed. Treatment, it is true, was freely offered in the past, but, from the grower's standpoint it was often painfully ineffective.

Although the taxonomic side is naturally predominant in the early stages of such a science as plant-pathology, this country has been noteworthy in having had for its exponents such thorough-going systematists as Berkeley, Cooke and Massee. The explanation of this doubtless lay in the difficulty the ordinary botanist experienced in identifying the fungi concerned, and later, in the official connection of Kew with the old Board of Agriculture.

The next phase to be developed—the detailed study of the life-history of the parasite and of the susceptibility or otherwise of the host—commenced as an epoch under the inspiring genius of Marshall Ward; and its supreme importance is manifest in the fact that this line of research is still being eagerly and successfully pursued. It was reserved until a slightly later period for research on remedial measures to be taken up seriously in these islands. Without in any way slighting the experiments of previous investigators this period may be said to have commenced with the appointment of E. S. Salmon, to Wye College, in 1906, and with the establishment by the Department of Agriculture for Ireland of a field laboratory in the wilds of Connemara for G. H. Pethybridge. These two workers, set out, amongst other things, to *control* American Gooseberry Mildew and Potato Blight respectively, and it is not surprising that their problems led them into the realms of chemistry, physics and biochemistry and entailed studies of the life-history of the parasite, its biological forms and its reaction to weather-conditions, to say nothing of attention to the host-plant, its cultivated varieties, suitability to soil and climate, characters as to cropping, and varying powers of resistance to disease. With the initiation of this phase the establishment of phyto-pathology on its own footing (as a science) distinct from mycology was complete. Subsequently its importance has become fully recognised, and a many-branched state-aided, phyto-pathological service has now been organised for this country.

In the campaign against diseases under glass, no worker has specialised to the same extent as Dr W. F. Bewley, or secured such eminently successful results in all aspects of the subject. In the book now published he gives from first-hand experience the methods of combating fungus diseases existing in the sea of glass-houses lying in the Lea Valley. The book though strictly scientific is written primarily for the grower. Out of its nine chapters, fungi as such are dealt with in three only, the remaining chapters being occupied with such subjects as plant-hygiene, physiological troubles, bacterial diseases, mosaics, fungicides and steam sterilisation of soil. In addition to dealing at length with the diseases of Tomato and Cucumber it includes

particulars of those of the Rose, Arum, Carnation, Chrysanthemum and other greenhouse plants. The author however is seen at his best in dealing with the major diseases of Tomatoes and Cucumbers, and no one has done more than he to elucidate their biology or to discover means of suppression.

We can confidently recommend the book to every grower as being the work of a thoroughly up-to-date scientific investigator, whose sound judgment and practical experience enable him to give the exact type of information required. It is equally essential to every pathologist and pathological library. Although not including such items as formal diagnoses and synonymy, and possessing only a short bibliography, it contains much first-hand and valuable information not found in any other book.

Should a second edition be called for a few corrections are necessary, the most important of which is the statement that *Septoria lycopersici* has not been recorded in Britain. The fungus occurred in several stations in England in 1907 (specimens being preserved at Kew) and it was for several years a scheduled disease under a D.I.P. Order of the Board of Agriculture. There is evidence also that the Index and especially the Bibliography were prepared in haste.

A. D. COTTON.

TREASURER'S STATEMENT FOR THE YEAR ENDING 31 DECEMBER, 1923

CASH ACCOUNT

Cr	£	s.	d.	*Dr*	£	s.	d.
Jan. 1: Cash at Bank	89	7	0	Postage	9	5	0
Dec. 31: Subscriptions				Stationery and Minor printing	6	7	5
A. Current	242	16	0	Treasurer	192	13	4
B. Arrears	14	11	0	Secretary	2	18	9
C. Advances	21	7	3	Balance at bank	88	7	10
Entrance fees	7	17	6	On deposit at bank	150	0	0
Contributions to cost of papers in *Annals*	58	8	0				
Composition fee	14	10	0				
Bank Interest		15	7				
Total	449	12	4		449	12	4

Audited and found correct: WM. B. BRIERLEY.
R. STENTON.

21 *January* 1924.

BALANCE SHEET

LIABILITIES	£	s.	d	ASSETS	£	s.	d.	£	s.	d.
Subscription in advance	21	7	3	A. CASH						
Liability on *Annals*, Vol. x	170	6	2	Current a/c	88	7	10			
Stock	67	15	8	Deposit a/c	150	0	0			
Cash balance	101	18	5	Subscriptions in arrears considered good	49	4	0			
				Contributions owing on papers in *Annals*, Vol. x	6	0	0			
				Total cash				293	11	10
				B. STOCK (estimated value of stock of *Annals of Applied Biology* with publishers						
				61 cases at 2*d.* each		10	2			
				28 bound vols. at 4*s.* each	5	12	0			
				Unbound vols. complete sets at 1*s. each*						
				Vol. 1 156 copies	7	16	0			
				2 152 ,,	7	12	0			
				3 147 ,,	7	7	0			
				4 135 ,,	6	15	0			
				5 197 ,,	9	17	0			
				6 103 ,,	5	3	0			
				7 74 ,,	3	14	0			
				8 70 ,,	3	10	0			
				9 70 ,,	3	10	0			
				10 77 ,,	3	17	0			
				Unbound odd parts						
				315 at 2*d.* each	2	12	6			
				Total stock				67	15	8
Total	361	7	6					361	7	6

The sum of £400 was invested in 1922 in Savings Certificates.

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